MODELLING INNOVATION ACTIVITY PROCESSES FOR GLOBAL FASHION MARKETPLACES

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ABSTRACT

This thesis presents the results of an investigation into managing and modelling innovation process activities for global fashion businesses. It explains the significance of today's fashion business globalisation and the alignment of process activities that form an integrated set of companies, which operate as a single, virtual, enterprise. Extant research in managing innovation for global textile and fashion businesses is reviewed and discussed to establish the starting point for the work reported; ideas and tools used in parallel research applied to other business environments for improving the management of innovation activities are also reviewed. Innovation management in this research was defined as 'managing process-based interactivity dependencies to achieve desired goals of novel competitive advantage in today's globalising fashion businesses, either by means of product or process development'.

The fundamentally critical issue of interactivity dependency within modelling complex process activities, and its characteristics are explicated using a taxonomy comprising dependency types, patterns and measurements with respect to activity-to-activity interactions and relationships. Prevalent approaches and methodologies for modelling interactivity process dependency improvement and development are critically reviewed and discussed. The limitations of the earlier modelling work provides evidence for investigating alternative methodologies aimed at improving the modelling of large complex activity systems.

In the course of the research, a methodological framework is developed, forming a disciplined procedure for modelling and managing dispersed process activities. The research framework advocates that the two generic dimensional attributes are necessary for inclusion in the measure of dependencies between activities; these two independent attributes stem from 'processing information vitality' and 'interactivity organisational governance' and are based upon utility preference theory.

Evaluating large complex activity structures is a NP-hard problem. The framework evaluates process activity performance using an adaptive evolution algorithm to generate nearly optimal, but good enough, solutions efficiently. An elicitation procedure was developed for obtaining the modelling input data; the modelling input data is derived from expert judgemental knowledge and subjective opinion.

Two case studies, concerning (1) the development of a novel plasma finishing technology and (2) co-ordination of globally dispersed product development teams, were used to illustrate the use of the framework and to elucidate the potential benefits from using the methods for assisting the management of structurally dynamic innovation activities. Finally, an additional life cycle framework is presented as a formalised learning process, through which enterprises could improve process performance continuously within an enterprise-wide learning mechanism. It is demonstrated that the framework presented has the potential to benefit those concerned with management and design of complex activity systems that feature high degrees of uncertainty and structure dynamics.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

1.1 The issues and the overall purposes of the thesis

It is widely recognised that in the context of the management of global activities, the modelling and integration of a large number of communication and activity processes is one of the most difficult research problems of recent decades. Much research has attempted to address similar problems. It is commonly contended that this kind of problem addresses a range of interdependent issues which are as varied as those encountered in rocket science research. Researchers from a wide array of disciplines have used sophisticated mixed-integer programming, relational databases, concurrent engineering, organisational design-and-redesign and similarly mysterious methods and tools in the hope that an expanding complexity of business and operational activities can be planned and integrated to develop and deliver customer-oriented products. However, the solutions to the problems are still undetermined and uncertain, especially in the process of innovation and product development in the early stages of a business cycle. The fashion business inherently involves changing and volatile activities. Modelling the innovation process for global fashion businesses therefore provides a range of challenging research problems. This research work aims to provide a methodology for improving fashion innovation processes, by building upon the results of earlier research, and also attempts to address the issue of process interdependency.

The research explores the characteristics of innovation in global fashion marketplaces and presents a new methodology to aid activity process planning and design. Further it aims to assist consistent communication and co-ordination; effective propagation of process changes; and evaluation of process performance and operation in accordance with market expectations. The issues at hand relate to several disciplines; process design; system and enterprise modelling; project management; concurrent engineering; marketing; manufacturing technology and information technology. These perspectives are integrated to support the positions presented in this research work. The goal is to build a bridge connecting these streams of knowledge discipline, from which a new perspective can be developed for the future. Rather than just developing an extension to extant theoretical knowledge in any of these disciplines, this research thesis aims to augment implementation knowledge. A methodology framework is formulated to aid applied researchers and practitioners. For industrial practitioners, this research provides a methodological tool which is useful for analysing and evaluating alternative process systems, and for designing seamless global point-to-point network systems.

This chapter serves as an executive summary, pinpointing the major themes of the thesis, and providing a research framework. An overview of the research methodology and the key points from each chapter and their dependence are presented. This research is mainly motivated by (i) the phenomena of the globalisation of fashion business and, (ii) the demand for integrated communication and activity configuration. The key deliverable can be regarded as a compendium of research outputs called virtual enterprise modelling (VEM). At the end of Chapters Two and Six, the VEM concept is presented in the context of this research.

1.2 Major themes in this research

The research focuses on modelling global fashion business innovation processes, which in essence enable the activity and decision integration across a number of inter-country enterprises in a very short period of time. Modelling the process is characterised by the following themes:

- **integrated enterprises that holistically co-ordinate sets of world-wide supply enterprises/activities in a single entity system:**

Integration between inter-country enterprises allows agility in manufacturing, emphasising short production throughput with quick changeovers. From a global supply chain perspective enterprises can manufacture components and assemble the respective end products in different parts of the world. The process flow and locations are determined by a set of different factors of comparative competence in terms of cost, processing time and effort of risk control. Determination of how to select and combine the activity processes to establish the optimal performance and cost structure is indeed very demanding. Through this research, an effort is made to evaluate strategically the process performance stemming from alternative process systems.

As shown in a majority of business activities, product innovation occupies the most significant proportion of the total supply cost. Activities form a chain of costs that accumulate additively as they are carried forward to the end marketplace and reach a total which is within a level of the customer's willingness-to-pay. To relate such concerns to product innovation requires a common integrated approach.

- **strong intertwining of dynamic business and technological factors:**

Studying the concepts of activity process modelling in innovation requires a contingent view, wherein the business environment issues should be considered. A process model concept should adapt flexibly, congruent with the changing factors in the macro-environment. Hypothetically, the research provides a basis on which appropriate forms of innovation activity processes can be designed and redesigned, pertaining to the various products and market environments within which global enterprises deal.

- **efficiency-advocated, lean product development and realisation that sustains quality and novelty without undesired design process iteration and resource misallocation:**

A major source of uncertainty in the course of innovation and commercialisation stems from the tendency of activity processes to iterate among a large number of activities which are interactive and inter-reliant. Problems in individual activities are likely to trigger repercussive problems toward interdependent activities. Inevitably, this nature of interdependency often results in undesirable reciprocal work and delay in delivering novel products into markets. In addition, re-working and re-scheduling of preceding processes result in an inefficient allocation of resources and facilities. This research is concerned with the nature of process interdependency and the tools that have to be developed to address such concerns.

- **market-orientation that brings involvement of all members of supply pipelines in the early stages of innovation processes:**

There should be a method of examination that links the crucial customer's requirements with an array of interdependent production and distribution competencies across enterprises. It needs to involve all the enterprises of a supply pipeline in the very early stages of innovation or new product inception. Collaboration becomes central to attaining successful innovation; this emphasises informal and consensus communication among functional and technical teams. Collaborative design and innovation processes should be based on sufficient co-existence of different perspectives which are themselves often domain-specific and characterised by various expert judgements and professional intuitions. How they interface becomes a crucial factor for ensuring proper exchange of abstract opinion and documentation of informal information. Indeed, most of the problems in developing and integrating collaborative processes stem from high levels of informal and abstract information interchange.

Throughout all the themes, modelling innovation can be regarded as both a subjective and an objective investigation, whereby a proposed strategic blueprint is devised to integrate world-wide activities of planning, producing, distributing, and marketing innovative fashion products. This can only be accomplished through a series of exhaustive process mappings that analyse, decompose and reorganise sets of process activities in the most appropriate way. However, the effectiveness of an innovation activity design is often attenuated by intractable changes in complex supply pipelines. The information that is specifically required for evaluating a novel process is often inadequate and imprecise. This situation may persist throughout the whole innovation process. To sustain more efficient innovation process planning and modelling, a novel methodology and evaluation techniques are needed.

In this research, the main objectives can be stated as follow:

(1) to extend the theoretical methodology frameworks for process modelling related to prediction and implementation of innovation within the context of global fashion businesses;

(2) to test the methodology framework developed in this research with reference to industrial cases; and

(3) to assess the potential value of the developed methodology framework for global-oriented fashion enterprises.

A key point is that, as a methodology research, the study uses a series of methods to explore and design agile processes for innovating and developing global fashion. The study employs both design and engineering management applications, an applied work with the aim of developing a methodology that is useful and can be implemented to guide further academic and industrial practices.

1.3 The context: fashion business activity process and process modelling

1.3.1 Fashion business activities

In recent years, fashion business investors have focused strongly on the strategies of either market expansion or cost restructuring to sustain their competitiveness. Many researchers (Abernathy *et al.*, 1995; Berger & Lester, 1997; Dalby & Flaherty, 1990a, 1990b, 1990c; Dardis *et al.*, 1988; Flaherty, 1989, 1996; Janice & Ananth, 1995; Zhang & Dardis, 1991) have mentioned such strategic views explaining the rationale behind the expansion of global operations. In the literal sense, global operations differ from international operations in the way that the former emphasises cross-enterprise and multi-terrestrial process optimisation and integration. Operations at several locations can perform processes for a given market and also a single facility can serve for several downstream operations in different locations (Morrison *et al.*, 1998). As such, globalising operations improve the responsiveness and cost performance, and are regarded as one of the most essential competitive competencies for today's world-wide market.

To appreciate the significance, consider the growth of global fashion distributors. Fashion companies, such as Liz Claiborne, Laura Ashley, Gap, C&A, etc. consolidate their region's demand into a single distribution volume for each season's new product lines (Dalby & Flaherty, 1990a, 1990b, 1990c; Hollis, 1996). Their world-wide affiliated buying offices then co-ordinate the dedicated sourcing and procurement processes for the different types of production capacity. Keeping close liaison with suppliers, these companies establish long-term supplier relationships and enjoy exclusive product novelties at very advantageous costs and delivery terms. J.C. Penny, Benetton and those companies stressing trend-oriented product development, use flexible world-wide co-ordination systems to develop and adjust different product portfolios for different regional needs. An additional beneficial value of global operations is the global learning with regard to comparative operational sophistication (Kogut, 1985; Kogut *et al.*, 1993; Kotabe; 1998; Porter, 1986). Today's global operations in the fashion supply chain are deemed as one of the most important inputs for developing performance excellence in the long-term. However, governing such performance should, in essence, be reliant on establishing a proper inter-relational framework for the entire supply chain, which is in turn subject to a dedicated activity process design and implementation.

1.3.2 Process planning and modelling

In regard to business activity process modelling, it can be viewed as a process of planning evolution that identifies, refines and translates the basic functional requirements into structural descriptions, and ultimately specifies a business entity or a "physical artefact" of organisational structure (Dixon, 1987; Scheer, 1998). All the knowledge of activities, technologies, facilities and human factors should be integrated through a series of abstractions to accomplish an activity process concept system. Using this concept system, we can specify the structural or physical requirements that can be used to deploy resources to attain the intended business performance attributes such as competitive cost, market responsiveness, global distribution, consistent and effective communication, etc. (Hubka & Eder, 1996; Wastell *et al.*, 1994). Succinctly, process modelling is indeed a pragmatic discipline concerning activity workflow and resource structuring within the capacity of the knowledge available.

The relevant science foundations in methodological process modelling are documented by a number of researchers: Hongo (1985) and Hubka & Eder (1996) provide definitions for design science and scientific study of process design activities. Checkland (1999) advocates soft systems methodology to model and re-engineer activity processes. Finger & Dixon (1999a, 1990b) comprehend a generic model of design and hierarchical organisation of concept knowledge for new product development process. For modelling agile processing systems, Suh's axiomatic design (1990) furnishes a theoretically tractable framework for multi-level process design and modelling. Concerning the methodological research in modelling process structure, Steward (1981) and Eppinger (1994) of MIT, suggest a model-based framework, a Design-Structure-Matrix, to manage complex and interdependent activities. Browning

(1998a, 1998b) further establishes a people-based activity decomposition and interface analysis technique to integrate new product development process. Mistree *et al.* (1989) models product and process design on the premises of decision-based compensation and selection algorithms. These researchers have contributed a remarkable foundation for understanding process design and its scientific application.

However, modelling business processes implies an inherent problem of identification of complex activity process structures. It relies highly on how much experience the model designer has and the knowledge of design methods and contextual constraints that can be perceived. Hence, a lot of extant academic works establish theoretic grounds and methodologies within a very limited scope of application. This is simply because detailed process knowledge might not be available, or may not be precisely predictable, or may be too costly to obtain in a complex business environment.

1.3.3 Relevant literature

Throughout the whole process of this research, the contemporary sources of relevant literature constituting the scope of this research knowledge domain and underpinning the foundation of research methodologies are extensively surveyed and reviewed. Conclusively speaking, managing global activities refers to the planning and monitoring system processes that are viewed as a network aggregating various points of operation so that the targeted performance throughout the entire supply chain is attained. Early studies (Dardis & Zhang, 1988; Singletary & Winchester, 1998a, 1998b) have covered such types of conception of globalising activities. Notably, one important area of research (Davenport, 1993; Earl, 1994; Hammer & Champy, 1993; Short & Venkatraman, 1992) contributing to this thesis emphasises the strategic use of information-related technology to design/redesign process activities and to achieve a radical change or total transformation of the entire business. Their seminal papers evidently take information science into consideration for modelling and managing activity processes. Some other literature concerns the empirical observations and implementing methodologies of process modelling, as mentioned beforehand. Researchers (Aalst & van Hee, 1996; Chen, 1996; Ould, 1995; Ross, 1997; Whitney, 1990) document a great deal of methodology framework and process modelling languages which, in later parts of this thesis, will be reviewed and discussed in detail.

Accommodating all the contextual knowledge of process planning and control, global strategies and novel business practices as a whole, we conceive a preliminary relational process model for global fashion business activities, as in Figure 1-1, and describe it as a system embodying the input-output relationships, corresponding process activities and process boundaries. Using Figure 1-1, readers of this thesis may better understand the essential context of global fashion businesses. The generic process requirements are decomposed and categorised as follows:

- Market anticipation
- Product /brand concept development and design
- Sourcing and procurement
- Production engineering and organisation
- Transportation and logistics

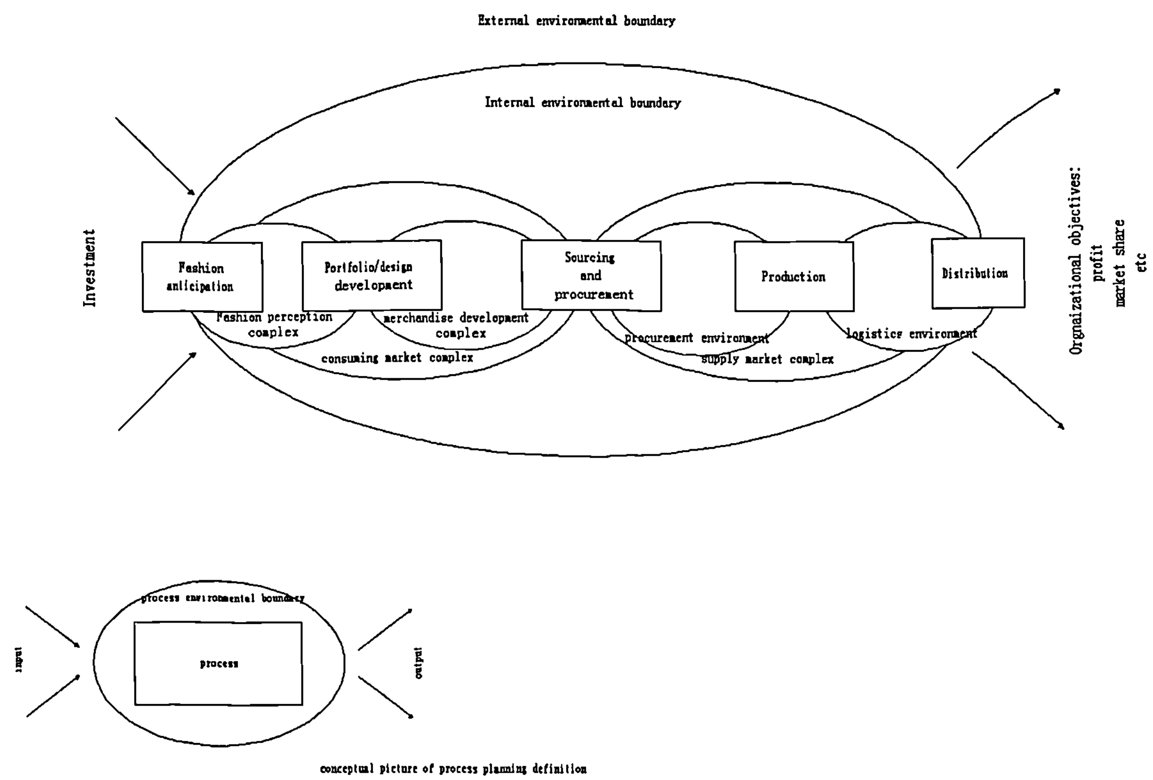


Figure 1-1 The generic activity process for global fashion business

Recapping, this research attempts to embody global fashion innovation using a set of process modelling techniques and methodologies to produce a framework, which improves the decision-making processes related to managing innovation activities. The investigation was aimed at extending the application of modelling processes to fashion products by building upon the results of earlier studies. None of the earlier work had attempted to address the issues related to a global environment.

1.4 Research framing process

The primary goal of this thesis is to establish an effective and contingency-based methodology that consists of a set of tools and techniques to be deployed systemically to design and model global fashion innovation processes. It is used to support modelling decisions that yield an effective structure of the innovation process, which is congruent with the market requirements and satisfies the business constraints. Thus, the thesis is methodology-framed. This section relates to the research framing process whereby this development is set forth. As a whole, the research process is composed of identifying the research goal, choosing the options available for framing the data and transforming the technical results into information which can in turn provide strategic options for managing today's globally oriented business activities. Figure 1-2 illustrates the major steps in the process modelling research cycle:

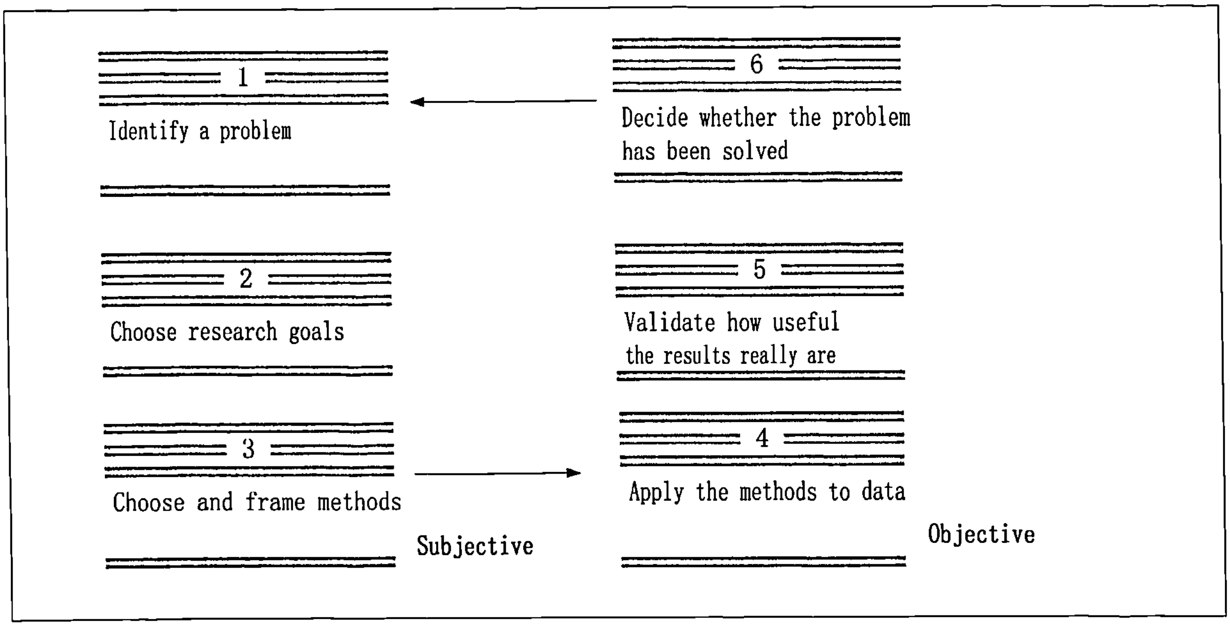


Figure 1-2 The major steps in research framing

In this figure, the research work concerning steps 1 to 3 is of subjective nature and from step 4 to 6 it is assumed to be more objective. In this thesis, Chapter Two and Chapter Three address the work of steps 1 and 2. These two chapters lay down the foundation concepts of innovation management and process modelling methodologies. Chapter Four refers to the work of step 3, which frames the methodology developed in this thesis to represent, programme and analyse innovation activities. Chapter Five presents two research case studies and illustrates the use of the framework proposed; this 4th step attempts to build and recommend process models that represent the behaviour of the innovation process structures in real cases. In steps 5 and 6, different potential outcomes of the process structures modelled are examined and validated in terms of the modelling construct and solution quality. Notably, the research process projects a cyclic process of organisational learning, wherein a mechanism is designed to diagnose process effectiveness and continuing improvement of activity process design and implementation. Chapter Six discusses the outcomes of steps 5 and 6 and the relevance of this cyclic process. It concludes with discussion of a life cycle concept for using the framework to attain various organisational objectives.

Notably, the main techniques adopted in the field studies belong to process/activity interface analysis (Browning, 1997; Shephard & Kirkwood, 1994; Wastell *et al.*, 1994). The process/activity interface analysis is an interview-based technique that elicits respondents to describe level-by-level how the interdependent global enterprise processes are structured to make up whole supply chain systems; described in detail in Chapter Four. The final section of this introductory chapter is a summary of the thesis content and the interdependence of the remaining chapters.

1.5 Thesis overview and the interdependence of chapters

Figure 1-3 illustrates the organisation and interdependence of the chapter material and depicts an overall view of the thesis organisation and the flow of the discussion logic.

1.5.1 Chapter Two: Survey: Review of contextual aspects of innovation management in global fashion businesses

This chapter discusses and explicates the motivation behind research in managing innovation for global businesses. The discussion encompasses a broad range of the extant research work in innovation from

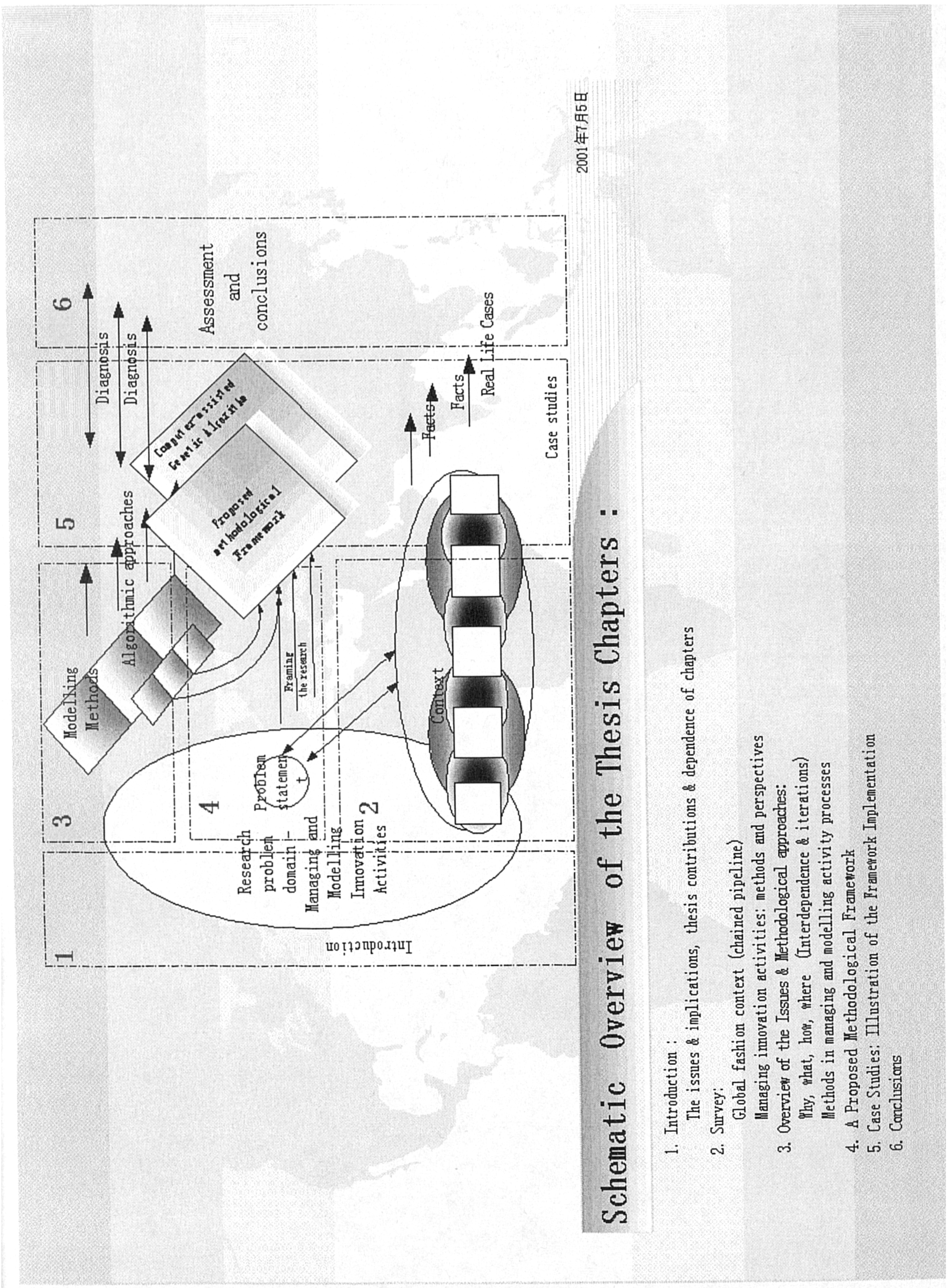


Figure 1-4 Schematic overview of the thesis chapters

the academic disciplines of marketing, engineering design, technological management, information management and organisation science. The purpose of this breadth is to enable readers of this thesis to understand the contextual aspects fundamentally pervading today's volatile global innovation activities. Several literature views of innovation are discussed: (1) innovation as managing activity-based systems; (2) innovation as outcomes of cross-functional co-operative work; (3) innovation as determined by a number of organisational factors and contingent market uncertainties; and (4) innovation as managing organisational changes for radical product and/or process improvement. The discussion also refers to the facets of today's inefficient co-ordination and management of global-scaled innovation processes, and the motivation towards the desire for better process performance and more agile process systems. On these premises, the chapter further presents two major schools of methodology-based process improvement study in current research. All the discussions attempt to comprehend a literature survey of current development and implications for managing globalising innovation processes.

1.5.2 Chapter Three: Overview of the related research and issues on modelling business activity processes

Activity-based innovation process modelling draws upon several fields of research. It is a wider, more general issue within project management and enterprise engineering. It is related to concurrent engineering, technology and product innovation management, and to a lesser extent, to some decision science models. In Chapter 3 we shall discuss interactivity dependency as a fundamental issue in modelling complex workflow processes; current management and technological tools often do not adequately account for the uncertain consequences which stem from this issue. Several modelling aspects are explored: the general process modelling methodology characteristics and their implications to management; the algorithmic objectives applied in computation analyses; and the types of modelling representation used in different process modelling paradigms in activity workflow design. On such premises, the relevance of and need for an improving methodology to address these modelling issues can be understood. The explanations and discussions of this chapter stem from a thorough literature survey of current process modelling development and the implications of modelling dependency-inclusive workflow activities for managing global innovation. This overview underpins the research strategy and so establishes the methodology framework in this research.

1.5.3 Chapter Four: Problem statement and the methodological framework proposed

This chapter frames and explains the research methodological framework. We present the rationales and the approach adopted in this research to model and analyse innovation activity processes for fashion and textile products. In brief, it addresses the research framework comprising the application procedure; the data observation and treatment; analyses of alternative process models; and evaluation of results. Specifically the framework assists in defining an activity process system, representation of process characteristics, and how a dependency-based method is used to show the characteristics and the manipulation of such characteristics to re-structure the processes. Based on the activity structures modelled by the framework, we progress to evaluating the innovation activity performance using a genetic (inexact) algorithmic strategy to schedule and optimise the expected to-market cycle time. Furthermore the framework calls attention to how key attributes and patterns of activity interdependency have to be recorded. A data observation technique is presented using a so-called expert knowledge elicitation to capture modelling data, which is largely characterised by judgmental and qualitative information sources.

1.5.4 Chapter Five: Case studies: Illustration of the framework managing and modelling innovation activity processes

This chapter is concerned with two case studies of the framework implementation. One study concerns a case of investigating and managing a novel treatment system development in an international silk manufacturing enterprise. This case study stems from an effort to introduce novel processing methods for textile products that can satisfy the future needs for flexibility in manufacturing and the environment requirements. During the course of the study, the company was evaluating a novel treatment method, using plasma, to improve the overall performance in textile finishing processes. The other case study concerns an international fashion buying company attempting to model and establish activity systems that can manage the existing product development operations more agilely and with more response to changing market requirements. Though the product development teams are very globally dispersed, they are required to work collaboratively to maintain a consistent and integrated world-wide cost structure, product image and quality. In these two case studies, the companies provide the observation, illustrating the use of dependency-based activity modelling methodologies to design activity process structure, which in turn significantly improve the innovation processes performance. Finally, an additional concept framework is generalised for strategic choice of designing and managing large complex business activities.

1.5.5 Chapter 6: Assessment and conclusions

This chapter discusses the validity of the framework and presents a corresponding framework life cycle used as a continuing learning mechanism. At the outset, we summarise the implications and contributions that the framework proposed in this thesis brings forth to managing global fashion innovation. Then the results and the validity of the framework applied in the case studies are discussed through a series of hypothesis reviews. Finally, the framework is extended towards a mechanism that entails the investigation of activity process systems as an organisational life-long learning cycle, and conclusions are presented on the future directions for the study of activity process interdependence.

CHAPTER TWO: REVIEW OF CONTEXTUAL ASPECTS OF INNOVATION MANAGEMENT IN GLOBAL FASHION BUSINESSES

2.1 Introduction

This chapter discusses and explains the extant research in managing innovation for global fashion and textile businesses. The discussion in this chapter is deliberately broad, encompassing research work in innovation from a number of academic disciplines including marketing, engineering design, technological management, information management and organisation science. The purpose is to establish an understanding of the contextual aspects which fundamentally pervade today's volatile global innovation activities.

At the beginning, we observe the nature of global fashion and textile businesses and attempt to generalise the global fashion and textile activities using a process-chain perspective. On these premises, we then explore different views of research in managing innovation that are believed capable of developing, or sustaining, global competitiveness. These views comprise (1) innovation as it affects the management of activity-based systems; (2) innovation as outcomes of cross-functional co-operative work; (3) innovation as determined by a number of organisational factors and contingent market uncertainties; and (4) innovation as managing organisational changes for radical product and/or process improvement. The discussion then consider the factors that result in inefficient co-ordination and management of global-scaled innovation processes. On the basis of these factors, we conclude with the target of better innovation process performance and more effective and intelligent methods to attain such performance.

The chapter continues with a discussion of two major process improvement and development approaches, (i) socio-technical systems and (ii) soft systems; these form the basis of the methodology used in this investigation. Following this, a taxonomy summary diagram is used to illustrate the range of literature sources of the research domain related to managing innovation process in the global context. Current research work on new methods for managing complex innovation processes is discussed at the end of this chapter. The chapter concludes with a survey of current developments and implications of managing innovation processes in global fashion and textile businesses.

2.2 Innovation management for global marketplaces

Very often, innovation management is closely related to the management of product or process development comprising a series of processes aimed at bringing products to marketplaces. At the same time, research in innovation is commonly linked to the management of changes (organisational re-design), since realising an idea, or developing a new product, will frequently require a certain extent of change in both technological and organisational aspects. This section provides a survey of extant literature concerning managing and modelling innovation activity processes in the global fashion supply chain. The value is in depicting the entire landscape of the research avenues related to this research work. The purposes of this section are twofold: First, it provides a structured review of process-based innovation management in the global fashion and textile supply chain. A parsimonious approach is presented to organise relevant information from a process-chain perspective, with citations of over one hundred and fifty seminal papers and texts, as listed in Table 2-1 (at the end of this chapter). Second, it sets forth the route by which the problems in this research work are framed.

2.2.1 The nature of global fashion businesses

Empirical studies in globalising fashion and textile manufacturing (Berger & Lester, 1997; Singletary & Winchester, 1998a, 1998b; Zhang & Dardis, 1991) show that traditional mass production is being driven towards agile, intelligent production by three major macro-forces, (i) emergence of a truly global marketplace, in which world-wide customers are served as in a single system but product offerings are regionally differentiable; (ii) accelerating technological advances that make the world-wide supply market more transparent and entail decisions made at the last possible moment for the future market environment; and (iii) emancipation of consumer rights that give a strong leverage to control world-wide business and product policies. These forces have indeed increased the volatility and vulnerability of global process operations. Such a turbulent and uncertain business atmosphere inevitably causes fashion and textile business investors to be concerned with ways of managing innovation processes, which have traditionally suffered from intractably long lead times and operational uncertainty (Berger & Lester, 1997; Dardis *et al.* 1988; Flaherty, 1996; May-Plumlee & Little, 1998; Zhang & Dardis, 1991).

Global operations differ from traditional international operations in the way that the former emphasises cross-enterprise and multi-terrestrial process co-ordination and integration. Operations at several locations can co-operatively perform processes for a given market and a single facility may serve for operations in several locations. By exploiting the variety of comparative advantages in process performance across different countries, global operations can achieve better responsiveness and cost performance. Indeed global operations are advocated as one of the essential competitive advantages in today's business environment (Kotabe, 1998; Hammond & Raman, 1995).

Empirical studies observe that the international fashion houses align with their world-wide buying offices to develop dispersed product activities and dedicated order fulfilment (Christopher & Peck, 1997; Dalby & Flaherty, 1990a, 1990b, 1990c; Ostic, 1997). Making use of various types of supplier management mechanisms these houses establish exclusive and novel product supply at very advantageous costs and delivery terms. Hollis (1996) and Abernathy *et al.* (1995) offer comprehensive discussion about such strategies of managing innovation in global supply chains. Metz (1998), extending the concepts and generalising the essence of good supply chain implementation, presents five key success factors. They include overriding customer focus; advanced use of IT; use of cross-functional teams; cross-enterprise integration and attention to organisational learning. These key success factors are actually to enable fashion and textile investors to manage innovation remotely on a real-time basis for different product portfolios for different regional needs (Graber, 1996). Indeed the benefits of an integrated and process-focused global operation have long been advocated by many researchers (Hammer & Champy, 1993; Graber, 1996; Flaherty, 1989; Kogut, 1985; Kogut & Zander, 1993; Kotabe, 1998; Porter, 1986). However, as discussed before, governing such performance is dependent on establishing the proper structural and relational parameters for the entire supply chain.

Accommodating these globalisation concepts into the fashion and textile business process for innovation, a generic model of the process chain is illustrated, as in Figure 2-1 (To & Harwood, 2000).

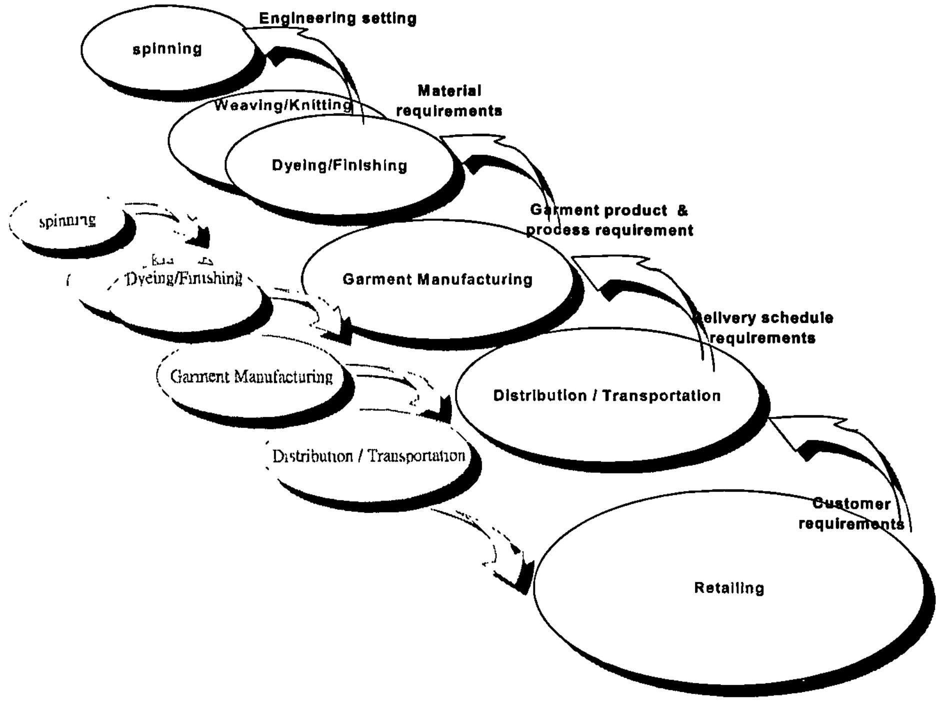


Figure 2-1 Process chain for fashion and textile businesses

The model corresponds with the global fashion and textile companies' dynamic business complex, which involves a chain of core activity processes from fibre spinning, weaving, knitting, dyeing and finishing, through to garment manufacturing and, consequently to retail distribution across different organisations and countries. A responsive and agile fashion and textile innovation system operates on the premise that once the customer preference and market opportunities are identified to the point that innovation requirements can be specified at a very detailed manufacturing level, all the process and resource planning functions can operate concurrently and inter-supportively. In such a context, a contingent global supply chain is established forming a holistic virtual enterprise. This virtual enterprise's functions involved in the designated supply chains are then aligned and integrated virtually. In other words, this chain concept brings the issues of logistics and manufacturing into consideration at the early stages of innovation. In this regard, many researchers have considered the problem from the organisation and information science perspectives and have contributed to the exploration of the determining factors, contexts and methods leading towards effective management of globalising innovation processes. Their work does however still not suffice to resolve, or even analyse, the problems of developing and modelling large complex innovation activity processes (Alder *et al.*, 1995; Ballou *et al.*, 2000; Bessant & Francis, 1997; Chiesa, 2000; Graber, 1996; Gupta *et al.*, 1986; Krishnan & Ulrich, 2001; Maccarrone, 1998; Meyers *et al.*, 1999; Milne, 2000; Millson *et al.*, 1992; Sobrero & Roberts, 2001; Spivey *et al.*, 1997; Trueman, 1998).

2.2.2 Views of innovation process management

This section attempts to extend the discussion in detail about different views of managing innovation process, especially in the global environment. Though the scope of discussion is broad, it focuses on a review for process-related innovation management research and links their implications for planning and modelling innovation activities to values of desired novel methodologies, discussed later.

2.2.2.1 Innovation as managing organisational changes for radical product and/or process improvement

This established view of innovation is seen as transforming organisation structure towards better productivity or profitability. This view has similarities with the views held by economists who regard innovation as R&D work, which brings about a radical change in productivity at the industry level or in an overall performance in society. Gopalakrishnan & Damanpour (1997) emphasise the point that innovation is both a response mechanism to environmental events to ensure organisational survival, and an organisational resource that can inspire managerial choice and selection to serve markets better. Research based on this view often focuses on the timing of innovation; it reflects on the speed and how pervasively an organisation's units respond to markets, by generating or adopting innovation, relative to competitors. Further, in most complex and capricious cases, innovation inevitably involves a certain extent of change in organisational structure (Abernathy & Clark, 1985). In the long run, these changes would result in some sort of organisational learning through which a better process is developed, commensurate with concurrent environmental requirements. As noted by Porter (1986), the strategic imperative for global competition is to re-configure value-added activities to exploit factor cost differentials and to extend competitiveness by co-ordinating interdependencies among activities across markets. This should be aligned with changes in the organisation structure and processes.

2.2.2.2 Innovation as determined by a number of overarching management practices

Researchers (e.g. Ballou *et al.*, 2000; Cross & Cross, 1995; Hollis, 1996; Kogut, 1985; Kogut *et al.*, 1993; Kotabe, 1998; Morgan, 1989; Paashuis, 1998; Ragatz *et al.*, 1997) use observations and qualitative techniques to explore, or model, various management practices that are contingently mapped with the environmental constraints across innovation teams and activities. Such management practices enhancing innovation processes include standardisation of data interchange; formalisation of inter-organisational relationships; goal consensus; inter-organisational competence assessment; co-location; etc. (Ragatz *et al.*, 1997; Fleischer & Liker, 1997; Reid *et al.*, 2000, Slusher *et al.*, 1989). These management practices are believed to empower innovation by three key aspects: intellectual, human and physical system configuration. In other words, the research focuses on strategic views of choice on context-specific management mechanisms to enhance integration and vitality of multi-party interactions in innovation processes. It can still be argued that the research does not explain and evaluate how much benefit is generated by the improved interactions, or to what extent the integrated activities should be achieved in terms of trade-off costs. Thus, we need a more detailed understanding of innovation processes.

2.2.2.3 Innovation as outcomes of cross-functional collaboration processes

This view of managing innovation processes focuses on the behaviour resulting from cross-functional or inter-organisational team contact during the course of innovation. Kahn (1996) distinguishes between interaction and collaboration during the communication process for product development and points out the philosophy behind these two communication contexts. In the early phases of innovation processes information is often vague and inadequate, teams are required to share, explore and resolve innovation problems, while differences arising from varying disciplinary opinion and judgement are maintained. The information exchanged is very often informal and sometimes abstract. Cross-functional teams should understand each other well and be committed to mutually agreed objectives and goals. Gupta (1986), Jagodzinzki (2000), Khurana & Rosenthal (1998), Perks (2000), Park & Cutkosky, (1999), Sobrero & Roberts (2001), To & Harwood (2000) and Whiston (1997) share similar views and emphasise the cross–functional collaboration process and its influence on choice of co-ordination mechanisms to manage inter-activity interaction. Crowston (1996) extends the view and categorizes organisational interactions between teams into three kinds of interdependencies which are based on the ways that the teams use organisational resources. They include: (i) share (the output of an activity is used by more than one subsequent activity), (ii) sequential (the output is passed directly to a following activity) and (iii) fit (input into an activity is required from more than one earlier activity). These research workers provide useful ideas on the different forms and contextual aspects of cross-functional interaction processes by taking into consideration human-related issues in process interaction and interdependency. However, it is difficult to measure how strong or how vital some activity processes are in their effect upon other activity processes. It is also difficult to estimate the consequences on the performance of an innovation process when the relationships between activities and teams change. The concept of dependencies in these cases is very psychometric and dependent on how people perceive and interpret the concept of interactivity dependencies. Past research has not addressed these critical issues sufficiently and the questions still remain unresolved.

2.2.2.4 Innovation as managing activity-based development processes

In most cases we talk about innovation as being related to changes in technology or within a technological context. In such research, innovation is interpreted as a development process; whereby a saleable product or improved process can be realised. The Organisation of Economic Co-operation and Development Frascati Manual's (OECD, 1981) definition is therefore commonly adopted:

"Technological innovation is the transformation of an idea into a new or improved saleable product or operational process in industry or commerce"

Krishnan & Ulrich (2001) adapted the OECD view and defined innovation as "kinds of product development that transform a market opportunity and a set of assumptions about product technology into a product available for sale". This view on innovation emphasises the management of activities as the route to timeously improving the product value in line with market requirements. Maccarrone (1998) categorizes fundamental innovation activities into five activities:

(1) definition and sharing of objectives of the innovation project;

(2) activity analysis aimed at identifying crucial activities and resources necessary to account for the successfulness of the project;

(3) process mapping by which activities are linked as chained processes following input-output loci;

(4) diagnosis analysis aimed at detecting variation of project progress and uncertainty to ensure progress alignment with the plan and/or alerting management to adjust the innovation in order to face the challenges of changing market requirements;

(5) finally, examining the choice of innovation control mechanisms such as cost reduction exercises and innovation performance benchmarking.

During the course of innovation, activities are planned/scheduled and the nature of the interactivity interactions (relationships) between the activities should be well understood and defined. Very often, research in this regard will directly point to the ways or concepts used to manage inter-activity interaction and the natural order of precedence of these activities. Such research interests are commonly found in areas of operations research, optimisation mathematics and decision science. How the activities interact is mainly based on the functions of the information and resources exchanged during innovation process (Clark & Fujimoto, 1989, 1991; Eppinger *et al.*, 1994; Kusiak & Larson, 1994; Millson *et al.*, 1992; Prasad, 1997;

Smith & Eppinger, 1997; Steward, 1981). Alternatively, since innovation is usually centred around technological issues, the activities are grouped/scheduled in accordance with the technical requirements of product innovation. Therefore activity interaction mainly accounts for exploring and resolving technical problems and converge on mutually acceptable technical solutions. Because of this, the intensity and direction of activity interaction can be anticipated using the correlation of parametric values of individual product components that the corresponding teams represent (Bloebaum, 1995; Bloebaum *et al.*, 1992; Cunningham, 1998; Kusiak & Wang, 1993; Malmströn *et al.*, 1998; Mistree *et al.*, 1989; Rogers, 1996). No matter which approach is taken, we may argue that innovation, being treated as an information or resource flow issue and as a sharing process, will understate the important role of human-related interaction and how this affects the efficiency and effectiveness of an innovation.

Based on such a view, innovation is regarded as some set of activity processes by which novelties are developed. Our discussion extends toward the major methodologies that are used to plan and model process-based innovation activities; these approaches are critically compared and discussed in the next section.

2.3 Global process improvement and re-design methodologies

Pragmatically, processes are inherently vulnerable because they flow horizontally, cutting across vertical functions of inter-country organisations. Therefore, the effectiveness of any process in a system is dependent upon process integration and the effectiveness and consistency of other processes. However, traditional function-based management concepts emphasise vertical differentiation and top-down hierarchical control. Operational isolation becomes obvious especially when enterprises or teams hold different policies and objectives. Bureaucratic formalities and departmental rivalries give rise to constraints which work against workflow processes running effectively throughout all the stages of a business cycle; when this happens, process performance is inclined to atrophy and improving and re-designing processes becomes contingent and uncertain (Cooper *et al.*, 1997; Paashuis 1998).

In the past decades, researchers have striven to address these issues from a range of different perspectives. As stated earlier, the marketing perspective view on process innovation is one which focuses upon the design and arrangement of a set of activities to improve product features and values to better meet end-user (customer) requirements (see Kogut & Zander, 1993; Kotabe, 1998; Morrison *et al.,* 1998). Organisation management perceives innovation as a series of human interactions and organisational communication to achieve a novel artefact. Methodological design and systems design address innovation using trade-off analysis among sets of performance parameters to define innovation process arrangement and requirements (de Neufville, 1990; Scheer, 1998). No matter from which view we see the innovation process, integrative and holistic process concepts are regarded as essential to enhance and ensure process consistency and standardisation (Checkland, 1999; Davenport, 1993; Kawalek, 1991; Ward & Peppard, 1996; Wastell *et al.*, 1994); diverse experience has led to the development of different types of process analysis and design methodologies. As a whole, two methodological approaches are generalised: soft systems methodology and socio-technical systems design.

2.3.1 Soft systems approach

Checkland (1981) advocates the soft systems methodology approach; this has attracted much attention in the information system field for the past decades (Checkland, 1999; Wastell *et al.*, 1994; Ould, 1995). In brief, this type of methodology encompasses three parts. The first part is to investigate the structure of the problem and capture a detailed picture. The second part involves disengagement from the real world setting into the field of pure system thinking. The structure of the real world system is then generalised and abstracted so that a conceptual model can be built to represent the essence of process flow. The last part is to compare the generalised system picture with alternative imaginary systems. Through a series of analyses and evaluations, constructive discussion is orchestrated, suggesting practical courses of action to improve the current process deficiencies, or to eliminate possible points where processes are prone to failure and atrophy. This type of methodology emphasises improvement, starting from diagnosis of current process deficiency and an anticipation of improvement; the process comes to an end where conclusions are drawn mainly on the basis of system conceptualisation and abstraction. Process modelling focuses on a diagrammatic picture of the overall process landscape, and supports strategic systems thinking for process planning and implementation. However, for novel process systems or systems that are beyond the scope that the system planners have experienced, a number of problems can arise for which the methodology approach may not provide adequate solutions. For instance the questions that need to be addressed will include the optimisation of the configuration of the essential physical facilities in the innovation processes; how the activity and communication processes are to be optimally sequenced and located; how the processes interact and what is interchanged; how schedules and resources constrain the process planning and design; etc. Though the approach does not guarantee effective development and management of innovation processes, it is still commonly applied at the early, strategic planning, stages of innovation to encompass the essential factors, e.g., intellectual, human and physical facility aspects.

2.3.2 Socio-technical systems approach

The socio-technical process systems design approach is based on the classic view of organisational management, in which social interchange forms an essential part of processes. The aspects of both technical contact and social interchanges are taken into account. The technical aspects refer to the process procedures and the technology adopted to ensure and enhance the innovation process work. Social aspects concern the 'psychological context' in which people interact with each other; the humanistic principles of participation, learning and empowerment are strongly emphasised in this approach. Many works (e.g., Wastell *et al.*, 1994; Earl, 1994; Miles & Snow, 1992; Khurana & Rosenthal, 1998) are very influential and recognise the importance of a balanced consideration between the technology factors and human process inputs. Current researchers, Milnes (2000), Jassawalla & Sashittal (1998), Bessant & Francis (1997), Perks (2000) and Trueman (1998) address process modelling and planning issues through various co-ordination mechanisms which are aimed at enhancing collaborative and integrative interaction among multidisciplinary design teams. The mechanisms mainly centre around procedures or systems that enhance the information or opinion exchanged among teams. Such aspects include data capturing and sharing, systems standardisation, skill training and inter-team information standardisation. In the long run, these mechanisms can be embodied as organisational learning and an enterprise-wide consensus on innovation direction, policies and steps is therefore promoted. However, these research ideas seldom take into account the issue of market vulnerability. Very often, customer requirements are vague and invariably inadequate right up to the point when the process planners are committed to make decisions. Once the market demand changes, process requirement adjustment follows, and consequently, both technical and humanistic aspects of process systems are reviewed and revised.

To summarise, the views discussed concerning management of innovation unanimously focus upon the issue of proper inter-activity interaction to achieve the desired organisational innovation goals, regardless of the point at which they start to look at innovation. Based on the discussion above, it is proposed to define innovation in the framework of this thesis as:

> "Managing process-based interactivity dependencies to achieve organisations' desired goals for novel competitive advantages in global supply pipelines, either by means of product or process development".

This definition of innovation acknowledges the value of studying the nature of processes comprising a series of collaborative and interdependent activities to achieve novel outcomes in a competitive business world. The research content reported in this thesis is pervaded by the relevance of this notion. It also inspired the search for a method that entails better understanding of managing process-based innovation activities for fast-paced global marketplaces.

2.4 Reference to be remembered

Table 2-1 summarises the sources of relevant literature that constitute the scope of the research knowledge domain and provided ideas and knowledge upon which the methodologies in this research were developed. These knowledge domains include concurrent literature and seminal papers on: globalising fashion and textile activities; business process restructuring and globalisation strategies; business process re-design; process design and modelling for new product development; theoretical modelling for process management; organisational innovation; managing project-based innovation; and the contemporary process design technologies; i.e. modelling languages, strategies and methodologies. The scope of the review was deliberately broad and attempted to cover all areas and relevance to managing globally dispersed innovation activities. As such readers of this thesis are provided with an understanding of the research landscape and the relevant taxonomy of the thesis.

Table 2-1: Extant Literature Domains and Sources Concerning Managing and Modelling Innovation Activity Processes for Global Fashion and Textile Marketplaces

Managing and Modelling Innovation Activity Processes

Sub-domains :		Selected References:			their problems focus :
Globalizing Fashion Businesses		Dalby & Flaherty (1990a) —(1990b), —(1990c)	Zhang & Dardis (1991)	Singletary & Winchester, Jr(1998a)	What are the key determinants for effective liaison and coordination in global fashion & textile businesses
		Ostic (1997)	Kotabe (1998)	Kogut (1985)	What are the critical perspectives in today's market-oriented global businesses?
		Berger & Lester (1997)	Flaherty (1996)	Wang & Kilduff (1999)	What is the configuration of global-oriented supply chain? How can it be implemented?
		Singletary & Winchester, Jr(1998b)	Dardis et al.(1988)	Leung & To (1999)	How do textile enterprises change for global-visioned operations?
		Christopher & Peck (1997)			
		Hammond & Raman (1995)	Hollis (1996)	Abernathy et al.(1995)	How do the customer requirements and schedule drive for improvement in global fashion businesses
Activity Process Globalization		Hammer (1990)	Porter (1986)	Metz (1998)	
		Hammer & Champy (1993)	Flaherty (1989)	Morrison et al.(1998)	What are the initiatives for process-based organizational re-structuring? How can they be addressed from management perspectives?
		Earl (1994)	Kogut et al (1993)		
		Miles & Snow (1992)	Kotabe (1998)		How can enterprises address contingent process improvement strategically?
Business Process Redesign -theoretic and pragmatic issues		Short & Venkatramann (1992)			
		Davenport (1993)	Ward & Peppard (1996)	Scheer (1998)	How do IT-based technologies address problems of process re-design?
					How does a people-centric methodology address problems of process standardization and monitoring?
		Kawalek (1991)	Wastell et al. (1994)	Paashuis (1998)	How can human-technology interface effectively through process modelling?
					What are major approaches for process design?
					How do diagrammatic modelling languages address problems of workflow process evaluation?
		Wastell et al. (1994)	Checkland (1999)		How can process systems be designed through specifying and analyzing processes in generalized sence?
		Paashuis (1998)	Cooper et al. (1997)		What are the rationales for cross-enterprise process improvement and integration? What are strategic issues faced?
Process Design for Product Development Integrativeness and Concurrency		Metz (1998)	Jassawalla & Sashittal (1998)	Mills (1998)	
		Ramesh & Tiwana (1999)	Smith (1997)	Slusher et al (1989)	
		Ballou et al (2000)	Krishnan & Ulrich (2001)	Khurana & Rosethal (1998)	What are the essence of designing and managing global supply chain and the way for achieving high level of agility and integration?
		Hollis (1996)			
		Trueman (1998)	Park & Cutkosky (1999)	Malmqvist & Svensson (1999)	How do methodological approaches address the problems of process redesign and integration?
				Badke-Schaub & Frankenberger (1999)	
		Milnes (2000)			
		To et al (2000)	Fleischer & Liker (1997)	Reid et al. (2000)	
		Prasad (1997)	Smith & Morrow (2000)	Ulrich & Eppinger (2000)	What are types of process improvement and standardization enablers? How can an enterprise's processes be analyzed and integrated?
		Fisher (1997)			
		Meyers (1999)	To et al. (1999a)	Vernadat (1996a)	
		Perks (2000)	Perks (2000)	— (1996b)	What is the configuration of physical supply chain?
Organizational Innovation		Maccarrone (1998)	Bessmat & Francis (1996)	Adler (1995)	What are the crucial stages comprising innovation activities?
		Millson et al. (1992)			How do the activity-based methodologies apply to managing innovation process?
		Crowston (1996)	Gopalakrishnan & Damanpour (1997)	Chiesa (2000)	What are the views of research in management of innovation?
					How can the research in innovation be categorizedd in a systematic taxonomy?
		Trueman (1998)	Spivey et al. (1997)	Kahn (1996)	What are the implications for collaborative inter-activity(team) interaction?
		Khurana & Rosenthal (1998)	Ragatz et al. (1997)	Sobrero & Roberts (2001)	How can integration mechanisms be chosen pertaining to context-specfic innovation processes?
		Graber (1996)	Perks (2000)		How can the organizational aspects,i.e human, intellectual and physical ones, be related to effectiveness of managing innvation processes?
		Chiesa et al. (1998)	Abernathy & Clark (1985)	Ballou et al. (2000)	How is organizational related to organizational learning and continuing improving?
		Gupta et al.(1986)	Meyers et al. (1999)		How can innovation be institutionalized formally across global enerprises?
Product and Process Innovation & Modelling	Theory	Suh (1990)	Vernadat (1996b)		
			Prasad (1997)	Hongo (1985)	
		Yassine (1998)	To & Harwood (2000)	Mistree et al (1989)	How can enterprise modellers determine process requirements and parameters?
			Steward (1993)		How can customer requirements be matched by process functions axiomatically?
			Finger & Dixon (1989a) (1989b)		
		Hongo (1985)	Braha & Maimon (1997)	Cross (1994)	What is the entire landscape of theoretic design knowledge and research domains?
		Whiston (1997)	Krishnan & Ulrich (2001)	Cross & Cross (1995)	What are the typology of design knowledge-decomposition of design knowledge?
				Badke-Schaub & Frankenberger (1999)	
		Austin et al.(1999)		Eckert et al. (2000)	
		Slusher et al.(1989)	Yassine (1999a,b)	Jagodzinzki et al (2000)	Which are the crulcal processes for product design and approaches?
	Managing Innovation Project	Prasad (1997)			
		Whitney (1990)	Smith & Morrow (1999)	Wiest & Levy (1977)	
		Steward (1981)	Vernadat (1996)	Kusiak & Wang (1993)	What is the planned timing and sequence of innovation activities?
		Steward (1991)	Eppinger et al.(1994)	Carrascosa et al. (1998)	How do fucntional processes and resource be designed and modelled from concurrency perspective?
		Wang (1995)	McCulleu & Bloebaum (1996)	Rogers (1996)	How will enterprises plan and model activity processes dynamically?
		Browning (1998)	Wang (1995)	Krishnan et al. (1997a) (1997b)	
		Baldwin et al. (1998)	To et al. (1999b)	Sarbacker & Ishii (1997)	How much variant will be allowed during the course of product innovation?
		Browning (1997)	Gunasekaran & Love (1998)	Park & Cutkosky (1999)	How will the enterprise teams be coodinated collaboratively?
		Krishnan (1997a)	Bessant & Francis (1997)	Ramesh & Tiwana (1999)	Can collaborative product development processes be formalized organizationally?
Process Management for product innovation	Modelling Languages and Evaluation Strategies::				Tools developed
	process-based	Ould (1995)	Hayes (1969)		
		May-Plumlee & Little (1998)	Wiest & Levy (1977)	Foulds (1991)	"Action/activity-based, graph-based languages
			Puterman (1994)		"State-based process modelling
		Reisig (1998a) (1998b)	Aalst & van Hee (1996)		"Petri-nets
		Hoare (1985)	Gruninger & Fox (1996)		" Process Algebra"
					"Simulation/Queuing modelling; e.g. rule-based simulation, process enactment simulation..."
	Information/parameter-based	Chen (1996)			"IT-supported entity-relationship models
		Kusiak (1995)	Sarki & Lin (1994)		"Functional Specification approaches, eg. IDEF, SADT,SIM, Workflow process modelling
		Mistress et al.(1989)	de Neufville (1990)		"Decision-based modelling"
	Dependency-structure	Kusiak and Larson (1995)	Hayes (1969)	Cunningham (1998)	"Precedence-based process sequencing"
		Eppinger (1994)	Wang (1995)	Bloebaum et al. (1992)	"Dependency matrix manipulation using heuristic clustering algorithms"
		Browning (1998)	Balwin et al. (1998)		
		Smith & Eppinger (1997)			

2.5 Contribution of the process development and management to innovation in the global context

Succinctly, activity process development and management in innovation for global marketplaces concerns the co-ordination and design of a system comprising globally dispersed and functionally differentiated enterprise activities. These activities are interdependent, using distinct but inter-supportive enterprises' competencies to accomplish the desired 'winning novelties' relative to the competitors. Today, interaction of such activities depends heavily on use of information technologies to connect geographically dispersed teams; or in other words collocate them virtually. Virtual enterprise modelling (VEM) becomes a natural end-product of such research. The creation of virtual enterprises naturally extends the concepts of organisational integration and economic efficiency in supply chain management towards more global operations. The integration and co-ordination of a globally dispersed enterprise's resources and activities are developed and maintained through innovating information technologies. It appears that one single enterprise comprising different organisational entities in different locations can centralise product development, sourcing and manufacturing and thereby quickly respond to the end market/customer requirements. In this research it is intended to benefit those concerned with management of globally dispersed product innovation processes in a fast-paced competitive business environment. In particular, the aspects of the methodology developed and implemented herein will be useful for enterprise-wide design, inter-country activity system planning and control of change. This section describes the currently known benefits in developing and modelling innovation process from the perspectives of values gained from VEM.

2.5.1 Seamless integrated infrastructure.

An established innovation process system relates to all levels of enterprises across countries and demonstrates a high level of inter-activity reliability and consistency. Modelling innovation processes in a single virtual enterprise allows planning, resource allocation, scheduling, execution and progress tracking over all stages of the whole business cycle. Hence, the information flow and resource distribution are integrated to support responsive and effective decision making at all levels.

2.5.2 Organisational learning and cross-functional collaboration

Based on the above point, managing and modelling innovation processes in a virtual enterprise gives rise to decisions made at the lowest possible levels with high degrees of autonomy and encourages team-based organisational structures, wherein people in teams share authority, responsibility and the abilities/skills of other people. At the same time, it can also bring the issue of logistics and manufacturing activities into consideration at early phases of product and process development. In such an operational environment, all enterprise units exhibit higher involvement and higher accountability; enterprise-wide long-term learning and development can be enhanced. Process-based innovation activities emphasise horizontal interaction and communication across well-partitioned functional or expertise units. Formal organisational communication cannot suffice to maintain effective discussions of innovation concepts through opinion sharing. Close and frequent interaction becomes crucial for people successfully to manage innovation processes where they communicate and interact very informally and unstructuredly; interactions are even more critical when large amounts of imprecise and abstract information are involved.

2.5.3 Process modelling for changes

Virtual enterprising emphasises alignment and interdependency of dispersed enterprises so that they act concurrently and responsively to capricious market environments. During the early innovation phases of the business cycle, the enterprises concerned are required to participate in process planning for product development, verification, testing, manufacturing, and deployment. Such participation can allow the enterprises involved to respond to any contingent changes holistically, through the use of easily controlled, shared information and documentation, within a virtual enterprise system model.

2.5.4 Selection of appropriate integration mechanisms

Table 2-2 lists key integration mechanisms which overarch the supply chain processes. Integration among interdependent activities is the centrepiece of virtual enterprise modelling and development. Innovation is inherently context-specific and involves contingently dispersed teams with diverse expertise. A successful innovation is inevitably reliant on different mechanisms to ensure accurate and sufficient communication among them. To ensure appropriate choice of integration mechanisms, we require to thoroughly understand the inter-team relationships and inter-activity dependencies. Hence, modelling a process-based activity system in a virtual enterprise is regarded as a vital precondition of today's global innovation activities.

Table2.2: The categorisation of integration mechanisms (To and Harwood, 2000)

	Technology-centric	People-centric
Integration enablers	System analysis and engineering; Combinatorial process design; Standardisation-for-information exchange; Virtual prototyping (e.g. CAD/CAM); Rapid real sample proto-making.	Team development; Team co-location; Standardisation-for-skill; Management-and engineering-for-change.
Integration keepers	Knowledge-based document management support systems; Real-time information sharing, mark-up & automation systems; Integrated messaging (e.g. computer-telephony integration)	Group thinking; Inter-team meeting; Telephone and videoconferencing.

In summary, an innovation process modelling framework should feature the following beneficial global environment propositions:

- It is cross-functional and promotes sharing in process design and development of the global fashion business activity system.
- It is capable of consistently and metaphysically generalising real innovation processes and performance
- It infers detailed interrelationships between activity processes for innovation planning, development, verification, testing and implementation and provides a baseline for future contingent redesign and organisational learning.
- Given detailed design descriptions and representations, it allows us to verify whether the designed workflow processes shows the desired performance. This proposition is also closely related to simulation, i.e. to derive alternatives based on possible process behaviour variation.

In the coming chapters, we shall present how these propositions are to be attained. Table 2-3, shows how each chapter contributes to the VEM's knowledge domain and practices.

Table 2-3 Contribution of chapter discussions to virtual enterprise modelling knowledge

	Chapter :			
Virtual Enterprise Modelling (VEM) practices	3	4	5	6
1. Identification of effective workflow process paths		√	√	√
2. Seamless point-to-point information flow	√	√	√	√
3. Rapid product prototyping	√		√	
4. Continuous organisational learning & knowledge management			√	√
5. "Virtual" collocation		√	√	
6. Team standardisation			√	
7. Integrated product/product family design			√	
8. Just In Time implementation		√	√	√
9. Trust and commitment in supply chain management			√	
10. Supplier data integration			√	√

2.6 Concluding remarks

In this chapter, the seminal and influential literature and research in innovation related to process development and management is reviewed. The review is deliberately broad in an attempt to define the starting point in the search for a better method to manage innovation activities for fashion and textile businesses. The definition of innovation management used in this thesis, framing the context in which the research proceeded is:

> "managing process-based inter-activity dependencies to achieve organisations' desired goals for novel competitive advantages in global supply pipelines, either by means of product or process development."

CHAPTER THREE: OVERVIEW OF THE RELATED RESEARCH AND ISSUES ON MODELLING BUSINESS ACTIVITY PROCESSES

3.1 Introduction

This chapter discusses interactivity dependency as a fundamental issue within modelling complex workflow processes; current management and technological tools do not adequately account for the uncertain consequences stemming from this issue. The chapter is organised as follows: firstly, the motivation behind and desire for better activity-based process systems and agile activity process co-ordination are discussed. Then a critical review and comparison of existing dependency concepts in different disciplinary studies is presented. In brief, interactivity dependency can be characterised taxonomically by the types of activity-to-activity interactions, patterns and measurements. Following this part, the major inter-activity process dependency improvement and development methodologies are surveyed and discussed. Empirically observed, the methodologies can be grouped into four major approaches, namely descriptive, schedule-focused, flowchart and policy-constrained approaches. Based on these, the methodology framework used in this research is described. The objectives of this discussion are to explore: (i) the general process modelling methodology characteristics and their implications for management, (ii) the algorithmic objectives applied in computation analyses, and (iii) the types of modelling representation used in different process modelling paradigms in activity workflow design.

In section #3 of this chapter, concerns are revealed about the characteristics and facets of process interdependency in managing and modelling large-scale and complex process-based activity systems. These explanations, which can apply generally to any process planning situation, include:

- difficulties in thoroughly discerning interactivity dependency in large-scale activity process systems;
- dependencies occurring beyond the limits of the model;
- activity modelling associated with sets of modelling assumptions. In most cases of innovation, situations are atypical and assumptions cannot always be made within the planners' experience and imagination;
- in normal structures, the process complexity is likely to be compounded by an increasing number of activities and by teams in different locations being responsible for these activities;
- organisational schedules and policies force decisions to be made and therefore forward immature decision information to other interdependent activity processes, rather than allowing iterative deliberation on technical aspects, i.e. restraining policies govern the co-ordination and ways of interaction among interdependent teams.

In the last section of this chapter, the relevance and need for an improved methodology to address these modelling issues is highlighted. The explanations and discussions of this chapter stem from a thorough literature survey of past and present process modelling development; they provide an understanding of the important issues related to modelling dependency-inclusive workflow activities for managing global innovation. Therefore this section actually underlies the research direction and sets out the methodology framework used in this research.

3.2 Process modelling: why, what, how and where

3.2.1 Use of activity process modelling

Modelling is itself an abstraction activity using symbolic representations to specify characteristics of systems and the interrelationships between components of the systems. Through the representation, users and designers can perceive the static and/or dynamic nature of the systems and infer more information than is derived directly from the model itself. In philosophical terms, the purpose of a model is to lay down a particular perspective that restricts the perception to the features that are believed relevant to the model's objectives (Schut & Bredeweg, 1996). Process-based activity modelling allows activity planners to refer to desired workflow processes with specified levels of detail within particular constraint frameworks, like overall cost and time. The models allow consideration of alternative sequences of activities and lead times based on flow of material and information, and/or the variance which is characteristic of the system modelled. Pragmatically, process-based activity models deal with the identification of critical and essential activities involved for effective workflow operation, their technical precedence relationships and the ways they interact with one another. Such types of model become platforms that allow planners to define priority of resource distribution, arrange optimal flow of information and material, diagnose potential deficiencies and remove critical points that may hinder consistent flow of work in a business cycle. The aim is to answer questions such as:

1. Subject to resource and policy constraints, what are the alternative process settings for optimal performance in terms of time, cost, degree of process certainty and process consistency?
2. More specifically, what points in activity models should be highlighted for focused consideration to ensure the maximum acceptable performance or the most significant improvement when compared with the current performance?
3. If business objectives are to influence results, which activities are essential? when are these activities initiated within the process? at what stage are the activities complete?
4. When activity planners are going to design activity systems, can the systems be easily represented and understood by all parties concerned? Can the system be traced or recorded formally?
5. When an activity system is proposed, can it provide guidance for teams to interchange opinion

collaboratively?

All these questions relate to the structure of activity processes in proposed systems and to the flow of information and/or material work through the processes. Global activities always pose serious problems of undesirably long lead times and a lot of unintentional process re-working and re-scheduling caused by a large number of interdependent activity processes spread across enterprises in different countries. This section will discuss how the current methods and approaches view and study the inter-activity process dependency, from what perspectives these approaches are applied, why the perspectives do not substantially reflect real life activity processes, and consequently, why these approaches cannot account for the predictive behaviour of process models. It also lays down the foundation for this research that the modelling issues have to address.

3.2.2 Perspectives of interactivity dependency

Many organisational researchers have studied dependencies between people in organisations and the types of mechanism for managing dependencies (Litwak & Hylton, 1962; Malone & Crowston, 1994; McCann & Galbraith, 1981; Rockhart & Short, 1989; Thompson, 1967; Victor & Blackburn, 1987). Typically, dependencies are conceptualised as sorts of necessary action relationships between two organisational parties or between the tasks that the parties happen to perform. The essence of dependency is situation-based on some form of control by one party over the outcomes and/or actions of another; alternatively it may be due to transfers of resources or information between parties (Crowston, 1996). It is very clear that we perceive and interpret dependency differently according to the perspective used: viewed from organisational and socio-system disciplines, it concerns how people manage interactions among their activities to achieve mutually agreed goals or resolve conflicting interests; in information management, a dependency concerns the ways that information is managed to proceed between computational tasks which determine interactions among people; and from the economic perspective, dependency is commonly referred to as structural controls or constraints that require forms of co-ordination to allocate and distribute limited resources among people or the tasks that people perform. Improper understanding of dependencies gives rise to various extents of organisational rivalry and conflict, resource misallocation, unintended process iteration and delay.

The works of Thomas (1957), and McCann & Ferry (1979) are useful starting points for considering the management of inter-activity dependency; these researchers note that dependencies can be either competitive or facilitative, and usually causes a range of difficulties for the people that are engaged in them. They suggest that as dependency between parties increases, increasing effort is required to manage and co-ordinate how they interact; alternatively, parties might re-arrange their work processes in the way that the degree of dependency is reduced.

Litwak & Hylton (1962) state that inter-activity dependency comes into being when two or more organisation activities must take each other into account if they are to accomplish their own goals. Similarly McCann & Ferry (1979) define existence of interdependency as "when actions taken by one reference system affects the actions or outcomes of another referent system" and they measure the degree of dependency in terms of the amount of resources exchanged, the frequency of transactions and the value of the resources among the organisational parties. On these premises, these researchers consider dependency as a result of resource interchange. Pennings (1974) divides dependencies into four sources: task, role/position, social and expertise. Since then, researchers have focused more on describing patterns of dependencies and mechanisms used to manage the dependencies, rather than merely explaining the effects of interdependency.

Thompson (1967) denotes dependencies as patterns wherein people interact. Three types of pattern are identified: (i) pooled, (ii) sequential and (iii) reciprocal, associated with various matching co-ordination mechanisms. He also suggests that organisations should firstly cluster groups with reciprocal interdependency as closely as possible; structuring those groups with sequential dependency next and lastly those with pooled interdependency are considered. In brief, the conception of dependencies in the organisational perspectives are mainly based on the patterns of socio-interaction between people and how the interdependencies are managed through choosing proper mechanisms. Different patterns of dependencies result in adoption of different co-ordination mechanisms to ensure effective flow of information and resources across organisational people. Porter (1986) extends the concepts and recognises the significance of interdependency among supply pipeline members across countries. He contends that long term global competitiveness is gained in two interdependent dimensions: configuration and co-ordination of (i) value-adding activities and (ii) value-matching activities. That is, high competitive performance can be attained by integration of the global organisations' comparative competence across markets. Understanding and managing the interdependencies become the key determinant factor for attaining such performance. This investigation yields a similar view, i.e. that examination of interactivity dependencies acts as a key element to support the co-ordination of process systems in an integrative manner and for the achievement of holistic effectiveness across all levels of organisation.

In contrast to most organisational researchers, researchers in the field of information and artificial intelligence have analysed dependency as arising between activity tasks, rather than people. This approach has long been regarded as carrying an advantage as it only concerns the characteristics of different patterns of activity dependency related to technical system structure. However, it may be very ineffective, even vulnerable in most pragmatic implementation, since the characteristics of a dependency are initially inferred from the technical aspects of the interactivity process; the human and organisation related issues such as policies and leadership that determine the crucial performance of activity interactions, are excluded. Because of this issue, a different, balanced, approach has been adopted in this investigation which analyses the characteristics of dependencies for managing process activities. This is discussed in detail in the coming chapters.

Researchers from technology and information science consider dependencies as mainly arising from input-output information exchange between pairs of activities, and have developed taxonomies to describe and examine the interdependent relationships (Briand *et al.*, 1996; Clark & Fujimoto, 1989; Davenport & Short, 1990; Eppinger *et al.,* 1994, 1997; Whitney, 1990; Malone & Crowston, 1994; Wiest & Levy, 1977).

3.2.2.1 Dependency patterns

This subsection discusses major patterns that constitute dependencies among activities and the implications of these dependency patterns for modelling interdependent activity processes. Critically, there are three major patterns: pooled dependency, sequential or inheritance dependency, and interacting dependency.

Pooled dependency. This means that activities do not vigorously interact in performing processes; rather they are dependent on a pooled source of information or resources, on which they commonly but separately draw. Very often, these activities can run in parallel and support the succeeding activities indirectly or refer to preceding activity outputs obliquely.

Sequential dependency. This means that a downstream activity, or task, depends on an upstream activity that has to be completed before it can start. Such downstream activity demands upstream information or resource outputs as necessary inputs to start the process. Meanwhile, managing sequential dependencies involves explicit sequencing and tracking processes to minimise or eliminate wasted effort caused by the downstream activity dependencies on upstream inputs. Clark & Fujimoto (1989) and Krishnan *et al.*

(1997a, 1997b) suggest overlapping product development activities in an attempt to reduce time; this is achieved through more frequent and earlier information transfer from upstream activities forwards to downstream activities. Krishnan also proposes to control the extent of interactivity overlapping using an evaluation framework, that comprises two functions representing (i) the impact of information evolved by an activity to its coupled activities and (ii) the sensitivity of iterative changes in these coupled activities. However, it seems very difficult to operationalise the framework. This is mainly because of the very dynamic nature of the two function curves which represent very context-specific interactivity dependencies for most of the system processes. This research issue is still under exploration (Krishnan & Ulrich, 2001).

Interacting dependency. In this case two activities or tasks must mutually inform each other and make use of each others' outputs to modify, refine or merely verify its own process outputs. One way to think of this is that activity A requires inputs from activity B, but activity B simultaneously requires inputs from A. A very good example is the practice of concurrent engineering process in which product designers and process engineers work together to define mutually affected product features and the corresponding manufacturing process requirements. Hence two activities are dependently interacted when (a) one activity must invoke the other and (b) they communicate via sharing of their exclusive information or data (Eppinger *et al.*, 1994). This interdependency implies an inherent characteristic of process iteration, whereby a series of process reviews and revisions are required to converge to mutually accepted solutions. Timing the activities becomes very uncertain and the process consequence and performance are subject to a number of uncertainty factors governing communication and information interchange between coupled activity teams. Austin *et al.* (1999), Browning (1998a), Smith & Eppinger (1997), Steward (1993) and Wang (1995) propose strategies and methods to decouple this interacting dependency in an attempt to reduce the possibility of undesirable process iteration. However these researchers do not fully elucidate how to measure and derive the criteria by which interdependent activities have to be decoupled. In this research, we develop a novel concept construct of interdependency as the key criterion to manipulate interactivity process dependency. This concept construct takes both the organisation and information perspectives into account. A detailed explanation of this concept construct will be provided in Chapter Four.

3.2.2.2 Dependency Measurement

The extant research measuring interdependency is prevalently based on the tangible exchange of technical information requirements that is needed to proceed activity tasks. The intensity of interactivity dependency is a measure of the importance and effect of information and/or resource exchanged between activities.

Often, researchers in engineering measure the strength of interdependency as the intensiveness and vitality of parametric information exchanged among coupled activities design (Bloebaum, 1995; Kusiak *et al.*, 1994; Kusiak, 1995; Rogers, 1996; Austin *et al.*, 1999). They decompose a product development project hierarchically into sets of design tasks or activities, each responsible for pre-determined system components, and suggest the use of difference equations to estimate the impact and sensitivity of changes of design parameters, initiated from one design activity, toward another coupled activity. The implementation is logically systems-based and particularly advocated in systems that can be unambiguously defined as a set of dependent variables. This measurement provides merits that assist in tracing the directivity of interactivity interaction and dependencies and provides hints about certain levels of interactivity dependency that are to be restructured for expected performance improvement. However, the measurement tends to suffer from exponentially increasing complexity as the number of system variables involved increases.

Browning (1998a), Yassine (1998), Yassine *et al.* (1999b), and Kusiak & Wang (1993) measure the strength of interactivity dependency using a predictive measurement approach. The activity participants psychometrically rate the expected levels of dependency in terms of how significantly dependent they are on the other coupled activities. The strength is scaled and referred reciprocally to the chance that activity planners can decouple or re-design the interaction between activities strategically and so ensure a maximal forward flow of the work process. On such a premise, the uncertainty in process iteration can be controlled for those activity processes which are "wrapped" together. The researchers study quite a number of cases and successfully operationalise the dependency measurements in large-scale product development projects. However, the data measurement is based on the opinion of perceived experience and confined to a very limited number of experts responsible for designated activity tasks. It raises a number of concerns about the validity of the measure. The term dependency is polysemic and there is no way to capture the absolute value of dependency; respondents may be using one (or more) of the following interpretations to interpret dependency:

(1) Forecast dependency. Especially in new product development processes, respondents rate the scale of dependency they would predict and anticipate.

(2) Role dependency importance. Respondents rate the dependency mainly according to the position and authority role of people involved in the coupled activities.

(3) Equitable dependency. The level of dependency respondents feel they ought to have in comparison with the dependencies of others.

(4) Attribute dependency importance. Dependency is a concept construct that may comprise a set of attributes, like the novelty of information exchange, impact of change of information, frequency of communication, the predictability and response to the counter-parties' information. Respondents rate the dependency according to their knowledge about the importance of these attributes.

Each of these interpretations is somewhat different and contributes to a considerable extent of variance and potential bias. The data integrity cannot easily be proved, it poses many data capturing problems to rationalise it for planning and scheduling the interdependent activities. Admittedly the prevailing project management tools, like stochastic PERT and CPA, also suffer from similar issues when measuring construct concepts.

Alternatively, Briand *et al.* (1996) suggested a normative classification of purposes for information exchange to define the strength of interdependency:

Modification: For pairs of activities, the output information or resources from one activity passing forwards to another for further processing is so vital that the outcome of this process will definitely be modified and changed; in this case their interdependency can be regarded as very strong and necessary. The information or resources may be used to redefine results of the process, or resolve the conflicting interests and directions. In other words, this dependent activity process is very sensitive to the changes and variation of the coupled activity and requires substantial re-work. Notably, people involved in these activities are prone to be grouped together and ensure close collaboration and frequent contact. It is especially significant when the information is vague and conceptual during the early phases of product development and major changes may be anticipated in order to embody novel concepts.

Refinement: To a less extent, the dependency still exists but the information exchanged would not lead to a very substantial change. The results of the activity process continue to adhere to the path of pre-specified solutions.

Extension: The major content of the interdependent activity results would not be changed during interaction. The information and resources exchanged are mainly used to verify or enrich the results of the process.

Notably, Briand *et al.* (1996) uses the normative classification of purposes, or interprets the impact of information exchange, to define the strength of dependency between coupled (nominally sequential) activities; respondents are required to interpret interactivity dependency in a controlled manner. The stability of the measure tends to increase.

3.2.3 Approaches for modelling and analysing interdependent activity processes

This section provides an overview and comparison of the major approaches to modelling interdependent activity processes. It discusses the weaknesses and strengths of each, the criteria for selecting these approaches, and the purposes and perspectives on which each approach focuses. In this area, Braha & Maimon (1997), Fleischer & Liker (1998) and Vernedat (1996) offer salient reviews on types of process modelling methods from the information and engineering management perspectives. The section attempts to generalise the methods and categorise them into four groups, based on their significance in representing activity-based process features:

- descriptive systems thinking approach
- schedule-based
- network
- phases and gates.

3.2.3.1 Descriptive systems thinking approach

In this approach, individual processes are investigated and each characterised as a normal operating procedure. For example in developing new fashion products, activity processes should consist of :

- identifying the current trend and target customer requirements
- developing portfolio work in line with current market directions
- co-ordinating prototype sample development and technical testing
- specifying production requirements and delivery schedules
- fine-tuning product features, production process and mechanical settings

This approach has attracted particular attention for the design of operational and information systems as a means for defining and integrating process requirements. In brief, the approach would pass through a few stages: at first the process planner or modeller investigates the process situation and describes the details of essential activity workflow and its possible alternatives. Secondly, the modeller disengages the processes from the real world into the realm of pure systems thinking. Conceptual models are drawn and generically used to describe the essence of the process systems and the inter-process relationships holistically. Finally, the modeller generalises the nature and characteristics of the systems and makes analyses at systems level. A comparison of related imaginary systems follows; possible practical courses of action are examined in order to develop a better solution.

Critically viewed, the descriptive approach cannot provide a pragmatic model of process-based activity systems. In most cases, the description of activity processes is very content-dependent. Though it provides a limited set of formal process procedures and rules, descriptive approaches tend to be neglected and not used. This 'off-line' approach can provide a strategic means for monitoring the progress of a process, but it makes no provision for assessment of process performance, such as the variance against scheduled progress. It is commonly criticised for being too static. The usefulness of the 'model' described is very often vulnerable because of inadequate thoroughness, which is very much subject to the personal judgement and perceptual views of the modeller.

3.2.3.2 Schedule-based approach

The schedule-based approach is primarily concerned with the timing of various activities. In essence, schedule-based approaches deal with the planning of timetables and the establishment of milestones through which workflow activities pass. Most of the schedule-based modelling methods emphasise the integration of flow of information and materials. Consideration of the estimated process duration, the technical relationships of dependency precedence among activities and, if applicable, the constraints imposed are also included. Using a Gantt chart is the typical method; wherein the activities are shown as bars occupying various lengths on a time horizon. It shows how activities are overlapped and where bottlenecks may occur. A Gantt chart is commonly used as a model of a project in which large sets of activities are entailed to sequence and schedule, maintaining the perspective of concurrency that a modeller can see and examine. However, Gantt charts take very little consideration of the possible time variations during the course of process flow, both intentionally and unintentionally. In reality activities are frequently re-worked or repeated, and do not just progress forward. A Gantt chart can only provide a baseline to show the dependency amongst activities very vaguely, and cannot fully account for the structural changes and duration of each process cycle (Taylor & Moore, 1980).

3.2.3.3 Network approach

In this approach, activity processes are represented with particular focus on the flow, or the directivity of dependency between processes. In the simplest form, charts in nodes (or boxes) and arrowed lines are drawn to describe the logical and nominal input-output flow of each process. PERT (Programme Evaluation and Review Technique) is a method which combines simple networking with timing information (Fisher *et al.,* 1985). PERT diagrams show the connections between tasks, the length of time consumed in processes and the start and stop points of time. However, the arrows in PERT diagrams only show the sequential timing dependencies. It provides no information about how other factors, e.g. resource constraints or management policies, may affect the flow of network. Critically, it does not account for the issue of process iteration arising from inter-activity dependencies (Vazsonyi, 1970; Wiest & Levy, 1977).

GERT (General Evaluation and Review Technique) is an extension of PERT that allows process looping, i.e. iterative forward-backward flow (Moore & Clayton, 1976; Neumann & Ulrich, 1979; Taylor & Moore, 1980). Event-based simulation is associated with the network analysis. However, once the number of activity processes grows, the network graph tends to be intractable and visually complicated. When applying it to real life problems, especially in large-scale project activity scheduling and modelling, the modellers find difficulty in discerning the complex interactivity dependency relationships. Furthermore, the structured order of the activities is fixed and provides little flexibility for managing changes during the course of the process.

Other types of network approach emphasise the flow of information. IDEF (IDEF0 1981; Sarkis & Lin, 1994) is a typical family of modelling tools of this type. IDEF is a structured evaluation and design method for graphical and textual description of activities, activity relationships, and information flow. It is widely applied to model systems and enterprises with hierarchical structures. Activities are nested or a system of activities can be decomposed into levels of process delineation, whereby users are enabled to consider the activity structure in various levels of detail. IDEF0 presents the flow of physical and intellectual objects. IDEF1x is a hybrid for describing the content of the information flows. IDEF3 is augmented by simulation analysis. Graphically, a IDEF is composed of a number of boxes that are linked to represent flow in sequential order. An arrow indicates one of the functions as a process input, control, and a facilitating resource or mechanism.

IDEF has strengths in describing activity precedence relationships and hierarchical similarity within the activity structure. The network gives a good sense of the order of activity and grouping of activity families. It provides a simple and organised model platform for people of all disciplines to use, without taking significant effort to learn and interpret. At the same time, it provides a very disciplined approach to ordering and prioritising activities in a network flowchart structure, making it easy for the user to model and analyse a growing number of activities as levels of detail increase. However, because of its nested representation, the nature of concurrency in activities in different hierarchical levels is prone to be hidden and not easily appreciated. Furthermore, the flow across different activity levels cannot be stated explicitly. In many pragmatic studies, use of a simple IDEF0 to model activity processes is very enlightening to all participants. However, when the number of activity levels increases, it is difficult to manage and view the model built in its entirety (Fleischer & Liker, 1997; Park & Cutkosky, 1999; Paashuis, 1998; Vernadat, 1996).

3.2.3.4 Policy-constrained phases and gates approach

The phases and gates methods look very much like a flowchart, but the primary feature of activity workflow is governed by a set of decision-based policies and criteria. In a specific phase, a set of activities must be performed in approximately the same time frame. The gate is a checkpoint, at which current evidence is reviewed, ensuring that preceding activities have been completed and verifies that succeeding activities are ready to start. In individual phases, activities are assumed to proceed without asking for additional or revised inputs from previous phases. It forms entry and exit criteria for activities to begin. The approach is widely adopted and accepted as good practice, especially when the activities are geographically dispersed and specialised (Miles & Snow, 1992; Morrison *et al.*, 1986; Ould, 1995). It also helps to resolve the resource distribution and location problems in planning globally dispersed activities. Using this approach, activity process management is mainly schedule-driven and predetermined by company strategic or operational policies. Therefore, it implies a philosophy of operation, which emphasises the importance of time and cost-to-market, rather than the process performance itself. However, because of its characteristics, the links (or interchange) between activities across different phases are restricted or even prohibited. Problems may arise from the inherent nature of indeterminacy of communication directions and timing during the process of new product development; wherein people interactions are very informal and involve a lot of cross-disciplinary issues. Iterative review of past decision and information has long been regarded as unavoidable and undeterminable from design perspectives (Bessant & Francis, 1997; Braha & Maimon, 1997; Cross, 1994; Hubka & Eder, 1996; Meyers *et al.*, 1999; Milne, 2000; Khurana & Rosenthal, 1998; Slusher *et al.*, 1989).

The discussion of this subsection illustrates that no single process modelling approach seems to embody all of the attributes required to address the issue of modelling and managing interactivity dependency. In this thesis, an alternative balanced methodology framework has been used, which is discussed in detail in Chapter Four.

3.2.4 Model Representation and Parameters

A number of researchers have developed models that explore different facets of planning interdependent activities (Clark & Fujimoto, 1991; Gruninger & Fox, 1996; Kusiak & Larson, 1995; Paashuis, 1998; Shtub *et al.*, 1994; Stoll, 1999; Ulrich & Eppinger, 2000). Most of these models are based on information flow or timing perspectives in new product development processes where individual activities receive, process and produce new product information for use by other activities. Generally graph and matrix representations are used.

3.2.4.1 Graph- and Matrix-based Representation

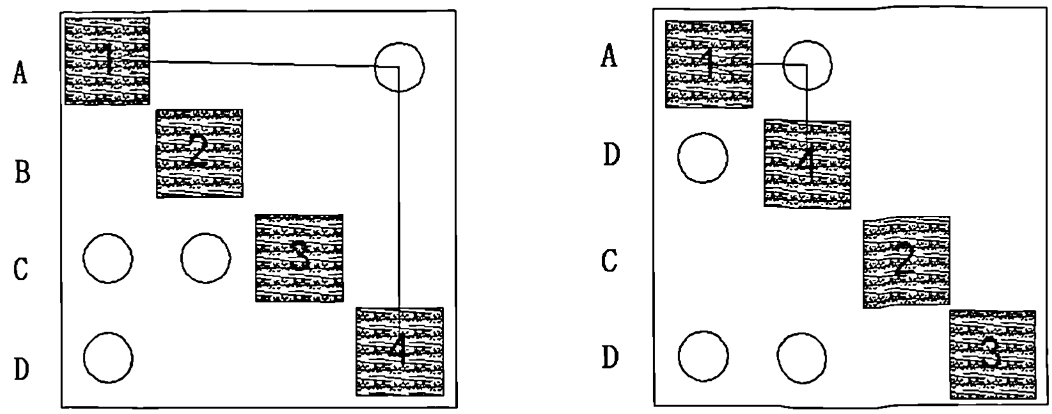
Graph-based methods have been widely applied to modelling activity processes. The best known include Gantt Charts and network precedence diagrams such as PERT/CPM (Wiest & Levy, 1977). The techniques were developed and evolved in the late 1950s for organising and representing project scheduling, relationships between activities and milestones in process systems. PERT (program evaluation and review techniques) was developed by the U.S. Navy at the end of 1950s as a tool for co-ordinating the activities of over 11,000 contractors involved in the Polaris missile programme. CPM (Critical Path Methods) was the result of a joint effort by DuPont and the UNIVAC division of Remington Rand to develop a procedure for scheduling maintenance shutdowns in chemical plants. The major difference between these two techniques is that CPM assumes that activity processes are deterministic, whereas PERT views the cycle to complete a process system as a random process, that can be characterised by a best, a worst, and a mostly likely estimate of its cycle. Over the years researchers have put forth a number of variants to represent and track problems of process structure and precedence, cycle time estimation, complex interactivity dependencies and the multitude of uncertainties found in complex new product development process management (Chen, 1990; Foulds, 1992; Moore & Clayton, 1976; Neumann, 1979; Taylor & Moore, 1980; Wiest & Levy, 1977). PERT/CPM is based on a diagram that represents the entire process system by a network of directed arcs (arrows) and vertices. The major approaches are either to place the activities on the arc (AOA) and have the vertices indicating milestones or checkpoints, or to place activities on the vertices (AON) and let the directed arc show precedence relations amongst activities. The model diagrams can be used to identify the potential time schedule for an overall activity system, to set optimal path of activity process flow and to improve co-ordination amongst the teams participating in the activities. Researchers have reported the benefits of these graph-based representation techniques (Clark and Fujimoto, 1989; Fisher *et al.*, 1985; Wiest & Levy, 1977). Technically, PERT/CPM is easy to use and understand. The theoretic properties of network graphs have been well and formally treated. Model diagrams can be easily codified for further computation processing. However, because of their ease of application, PERT/CPM are prone to be misused (Vazsonyi, 1970). Furthermore, discerning the detailed relationships between the activity structure and the process cycle time is problematic (Browning, 1998b). The ordering of the activities remains fixed and does not allow for review of potentially better alternatives. When the number of activities grows, it is problematic for users to understand and visualise the whole process. The computation resources required for analysing the feasible solutions are also relatively expensive and exponentially increase with the number of activities. In practice, the techniques, though often promoted, are seldom applied effectively to large and complex activity process modelling and planning tasks.

Eppinger *et al.* (1997) used a flow graph model to analyse the distribution of the expected cycle times for stochastic activity processes. The graphs model iterations using a probability rule and there are no constraints on activity duration. This model is much less tractable for concurrent activities and the output is a distribution of total effort, not duration. Wang (1995) used a graph-based Markov process to re-sequence and re-group the design teams, and estimate the uncertainty of process performance and cycle time. To rationalise the issues of process iteration, Wang proposed a learning process for activity process rework: stationary transitions decrease the time for each iteration (process re-visit) and dynamic transitions decrease the need to reiterate per iteration. These proposed graph-based models address the issue of improving efficiency for new product development teams to interact, constrained by sets of interdependencies.

3.2.4.2 Precedence and dependencies in dependency structure matrices

An alternative way to represent the structure of activity processes is to use a matrix format. This representation is intended for use when there are a large number of interacting activities whose precedence relationships and structure cannot be clearly represented in a graph. Steward (1981, 1991, 1993) and Eppinger *et al.* (1994, 1997) propose a square matrix construction, so-called design structure matrix, to represent the interacting relationship and the dependence among designated activities in a design process. The activities are arranged down the left hand side in the rows of the matrix and from left to right in the columns to from the square matrix. The activities are listed in the roughly chronological order that they are expected to perform in the process system. Symbols are therefore applied to populate the matrix, showing from which point activities feed information forward to, or receive information backward from another downstream activity. The symbols that are placed in a column imply information provision from that column activity to others and the symbols that are placed in a row imply information received from other activities to that row activity. In an activity-based design structure matrix, the symbols signify information flows between two activities: reading across a row reveals the sources of inputs to an activity, and reading down a column indicates where the outputs of an activity will provide input into other activities.

Figure 3-1 shows the examples of matrices representing interactivity precedence and interdependency. The relationships between the activities are indicated as off-diagonal elements in the matrices. The relationships can be simply qualitative symbols or numerical values that facilitate more detailed analyses using various heuristics of clustering. The aim of such a matrix is to represent the structural nature in terms of interactivity dependency and re-sequence those activities so that the optimal performance of the overall process system can be attained and visualised in a holistic manner. See Figure 3-1b. The performance variables can be spatial, temporal, and parametric types, depending on the different problem domains. Its strength is in handling dynamic analyses with the changes of process relationships and changes in process structure. To engineer changes in points of the process sequence, discrete event simulations can be incorporated to investigate the possible impacts.



(a) original process sequence (b) re-sequenced DSM for less iteration

Interdependent relationship

Fig 3-1. Examples of relational structure matrix

Eppinger *et al.* (1994) and Browning (1998a) applied the matrices to model iterative design processes amongst engineering design teams. Instead of using symbol marks to indicate interactions and dependence, they use numerical ratings to show levels of dependency among different design tasks. In effect, a weighted, multi-attribute objective criterion is proposed to attain relative dependency ranking. Browning (1998a), Cunningham (1998), Smith & Eppinger (1997), Smith & Morrow (1999), Steward

(1993) and Wang (1995) have elaborated on such modelling methods and reached many similar conclusions: once a structural matrix is restructured by "tearing" appropriate off-diagonal dependency elements (temporarily eliminating and ignoring a dependency relationship), a more effective activity process sequence can be explored and evaluated. An aim is to reduce the possible number of process iterations among activities, so reducing unexpected and undesirable process re-working time and cost. However, the computational cost of evaluating alternative breaks or tears is exponentially proportional to the number of activities and the extent of their dependency. It poses serious problems for handling large and complex activity structures. Because of this reason, Rogers (1996) has developed a software application using a genetic algorithm to evaluate the design structure matrix for complex design activity projects in NASA. Other research has been concerned with use of the relational structure matrix to model interdependent activity problems. See Figure 3-2.

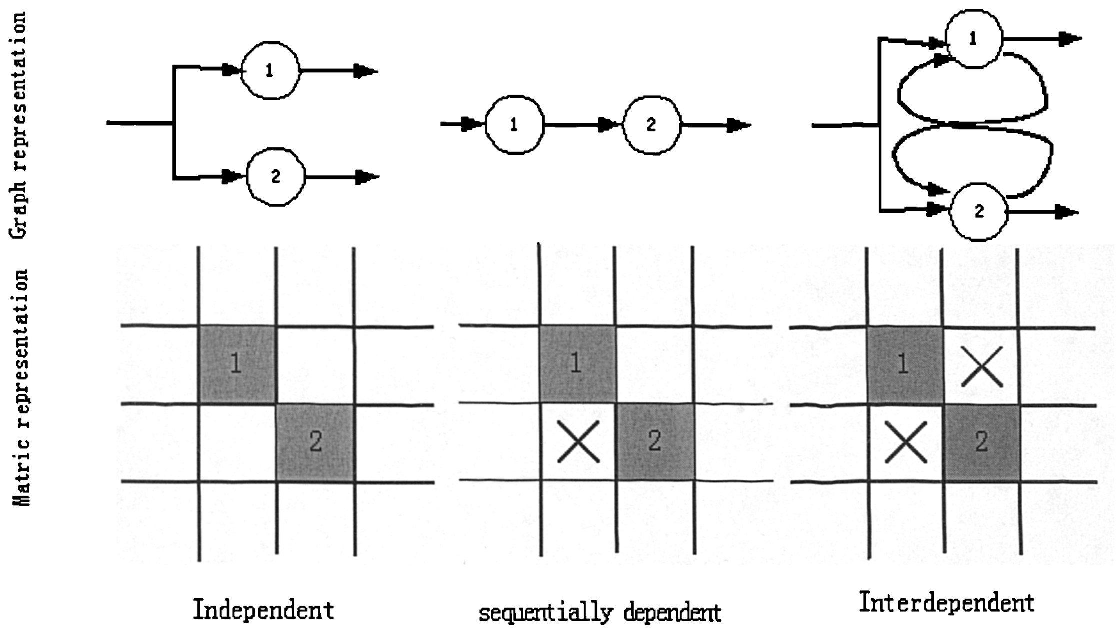


Figure 3-2 Process sequence and dependency structure matrix

Eppinger *et al.* (1994) and Krishnan *et al.* (1997a, 1997b) study the impact of overlapping evolving activities; they introduce the concept of sensitivity to rework, stemming from information changes of interdependent activities, as a measure of the strength of interdependency. Matrix-based representations are adopted to illustrate the types of dependency characteristics among interacting processes and people. Baldwin *et al.* (1998), Rogers (1996), and Browning (1997, 1998a) apply such dependency-based matrices to study optimal cycle time and to simulate sets of performances of design processes. Indeed, similar matrix-based methodologies have been advocated for decades in systems engineering. Hayes (1969) introduces the activity precedence matrix to study network flow. Kusiak & Wang (1993) represent and decompose the relationships between tasks and design parameters using an incidence matrix. Steward (1981) initiates formal treatment and application of these dependency concepts to integrated process design. Researchers at MIT (Whitney, 1990), Loughborough University (Austin *et al.*, 1999), and Chalmers University of Technology (Malmströn *et al.*, 1998) coin the nomenclature, Dependency Structure Matrix (DSM), as a general term for such types of methodological representation. In this research, we adopt a dependency-based matrix representation as a part of the work for modelling and analysing the structures of innovation activities. Its implications and effectiveness will further be discussed in Chapter Four.

3.3 Why the issues of interactivity dependencies are not thoroughly addressed

Based on the extant literature and observations for planning and modelling dispersed activity workflow process, the process performance is very dependent upon the extent and type of interactivity dependencies. The interdependent nature in interactivity communication and operation leads to problems of uncertain and intractable process iteration, and conflicting organisational rivalries. Why the interdependencies among activities are so difficult to take into account during activity planning and co-ordination is discussed in the following section.

3.3.1 Ignorance of dependencies

Not everyone involved in globally dispersed businesses discerns the existence of different dependencies, both in terms of the nature of the dependencies and their strengths (relative importance). Instead, some treat the dependencies equally and are reluctant to differentiate between inter-activity relationships. In most cases of coupled activities, they think of process iteration due to interactivity dependencies as part of a continuous workflow process, and see the re-work as specifically revisiting particular analyses and decisions, not as repetition of the same activities. Because of this, the rework becomes as an entirely separate activity. This is well illustrated in PERT chart modelling, where activities are more "sequential" and any undesirable extension of a process cycle may be unconsciously hidden and neglected. Consequently, people are reluctant to, or very conservative in, initiating their own processes, or running them concurrently with other activities, until adequate information from preceding activities is perceived to be available.

3.3.2 Dependencies exist outside the level of detail of a model

Very often, interdependencies arise between activities across very low levels of organisational hierarchy. Not every person involved will understand thoroughly all of the issues of dependencies throughout the different stages of a business cycle. Existing models are seldom capable of either representing and capturing dependencies in a holistic manner or illustrating the repercussion effects on each of coupled activities across all levels of organisational activities. Indeed interdependencies among "small size" activities occur very often, but may not appear in an aggregated model. Interactions between these activities are deliberately neglected because of their low status, or the high cost/effort of taking them into consideration; in other words, they are outside the level of resolution used in the model. However, recognising dependencies between small size activities may lead to a more effective arrangement and ordering of the workflow processes, which in turn could lead to faster and more efficient information updates and interchanges as a whole. Further, existing modelling methods seldom advise activity process designers on how to decide the level of detail that the dependencies should represent and analyse.

3.3.3 Atypical circumstances

Existing modelling approaches to re-designing and re-scheduling activities cannot responsively reveal the problems associated with the consequences of interdependencies, simply because many people regard global business activity modelling as very unstable when applied to atypical circumstances. Hence, there seems no value in describing activities with specific, likely interdependencies. Interdependencies imply that teams communicate reciprocally to achieve mutually accepted conclusions and solutions. To control the impact and consequence of process iteration, understanding inter-activity dependencies is a prerequisite. Improper ordering of interdependent activities may give rise to unnecessary review and revision of dated information at the very last stage of a business cycle and trigger a larger number of "in-between" change activities as knock-on effects.

3.3.4 Complexity of analysis

Interdependencies among activities further implies the evaluation of activity structures and the corresponding impacts on the overall activity process system performance. However, such evaluation is often tedious and demands unbound analytical efforts and costs. To model a large number of interdependent activities for optimal setting of the activity structure, a fast and intelligent evaluation method is a pre-requisite, but this is still under exploration today.

3.3.5 Organisational dependencies

In most cases, global activities are schedule-driven and controlled to a great extent by sets of enterprise policies governing the inter-activity dependencies politically, rather than merely based on technical information concerns. To model and manipulate such activity systems, organisation perspectives on dependencies should be taken into serious consideration. However, measuring and integrating such human-inclusive dependency aspect for evaluation of process system is very subtle and indeterminate.

The above facets account for the prevailing phenomenon of existing modelling vulnerability to represent inter-activity dependencies, especially in globally dispersed process systems. The overall challenges in the context of developing and modelling global fashion innovation are summarised as follows:

(1) making people aware of the existence of interdependency issues in the course of process activities

(2) making people aware of activity iteration as stemming from interactivity dependency,

(3) exposing the nature, and attributes, of dependency which exists among coupled activities

(4) operationalising and proceduralising the measure of interdependencies

(5) linking desired dependencies between activities to account for process performance in very short cycles.

In the next subsection, we shall extend the discussion above into a desired modelling framework that can properly address the points articulated.

3.4 The need for and relevance of an extended modelling framework

The explanations for a lack of planning and modelling techniques which fully account for interdependency underlies the need for developing dependency-aware models for large-scale processes in global businesses. Managing dependencies is fundamental to effective co-ordination and integration of well-partitioned teams and activity tasks. Yet to adequately represent and analyse some of the characteristics of complex and global dispersed business activities, existing dependency-based modelling frameworks need to be extended and become more "intelligent". The following subsections discuss desired modelling framework capabilities in relation to the characteristic points articulated in section #3.

3.4.1 Better interactivity definition

Although existing modelling approaches reviewed in this chapter account for issues due to inter-activity dependencies, their ease of use and ability to fully reflect the realties of dependency vary. Most of the existing workflow modelling approaches are based on a crucial concept in which activity structures are traced and defined by processing of information flow. Organisational teams involved in these coupled activities are inclined to process identical work repeatedly, but "perceive" the activity to be in progress, i.e. moving forward. An extended modelling framework should therefore make it clear that the definition of activity processes is based on achievement of the desired results and objectives that the teams are to accomplish, rather than merely a series of steps of information input-output flow at each step of activity documenting.

3.4.2 Levels of detail inquired and structural jujitsu points

As explained in the previous subsection, activity planners face many subtle difficulties in determining the scope and level of abstraction that ought to be included in a model. When an activity process planner makes a very simple analysis of a large activity process problem, including breaking an interdependent interaction between two small size activities, an opportunity for some very significant improvement may be allowed. Steward (1981) refers this to the paradoxical laws of systems:

(1) If we consider only a small part of this system, some other part you did not consider will very likely hide an effect of critical importance.
(2) When you consider the larger system, the problem becomes more complex.
(3) If the problem becomes too complex, you cannot deal with it.

While suggesting an extended modelling framework for activity process systems, we should take a number of questions into consideration:

(1) How much improvement in terms of accuracy (variance) can be made to the estimated or expected performance of an activity system model when an additional level of detail is included?
(2) How much cost and effort is incurred in an attempt to achieve a higher level of detail?

These two questions actually pose a further question, looking for what we call the 'jujitsu point' in the system structure. In jujitsu a minimum effort is used to manipulate a stronger opponent. As we use the term, the jujitsu point is where a minimum cost or effort can significantly alter (or improve) the performance of a large complex system in the desired way. Therefore, an activity process modelling framework should not just allow re-organisation of system information which management and experts originally supply and understand. Instead, it can appear in a form that helps enhance their insight into how the pieces of the system act together. Warfield (1976) and Steward (1981) refer to this type of analysis under the name of Interpretative Structural Modelling. Chapter Four of this thesis will discuss the formulation of a framework that deals with problems interpretively.

3.4.3 Contingency-based modelling

Existing modelling approaches for activity process systems also assume that a set of activities will not, or will seldom, vary the content of the activities. When developing novel products for globally dispersed marketplaces the set of activities cannot always be easily foreseen and predetermined. In this situation an activity process planner may be unable to know contingent dependencies in such atypical and complex circumstances. A modelling framework is required that is more robust for defining and documenting how activities are assembled for a "chained" process; the modelling framework needs to provide for prompt measurement updating of interactivity dependencies or incorporate a scenario analysis capability for strategic choice of process structure. Chapter Four includes a discussion of how an instrument developed by the framework proposed in this thesis can effectively and diagnostically define activity bounds and measure the corresponding interdependencies in terms of both the type and strength of the interdependency.

3.4.4 Novel concept construct of interdependency

We are not purely concerned about the structural characteristics of a system that determines information input-output relationships among the component activities. When measuring inter-activity dependencies, we also consider the organisation aspects that determine how people interact in the system. To assess such dependencies, we should recognise that we need to construe a concept that represents interactivity dependency, and the strength of that dependency. Modelling approaches reviewed in the extant literature cannot thoroughly address this issue. Yassine *et al.* (1999a) proposes to use a joint-attribute construing interactivity dependency: one attribute concerns sensitivity to the changes in a succeeding activity of a preceding activity; the other concerns the difference between the information (or decisions) actually sent from a preceding activity to the succeeding activity compared to the anticipated nature of the information. However, Yassine does not explain how these two attributes are validly associated with a single coupled dependency measure. In the present work, the measure of interactivity dependency is extended to include an additional attribute, the organisational governance from a preceding activity to its succeeding ones. To convert these attributes into a single, meaningful scale, a utility theory measure analysis of multi-attribute objectives is applied. It will be further discussed in the coming chapters.

3.5 Concluding remarks

This chapter presents rationales for effective modelling activity processes as one of the fundamental requirements to sustain and enhance competitiveness in today's changing global market environment. In the process of innovation, a number of globally dispersed activities are involved and demand an effective modelling framework to plan and co-ordinate how the activities interact and in what order they should be sequenced. Understanding dependencies among them becomes crucial in this regard. In the discussion, several theoretic perspectives of dependency, mainly from organisation and information disciplines, have been presented. Further the concurrent development of dependency-based activity modelling methodologies is in explained in detail covering a number of the widely-advocated approaches and ways of representation. Studying the failure of current modelling methods in terms of their ability to address thoroughly process interdependencies highlights ways for the exploration of a more powerful methodology.

In the coming chapters of this thesis, the methodology framework for this research is established and applied to the real life problem in managing innovation in global fashion and textile businesses. The overall methodology framework of this research is presented in Chapter Four. Two detailed case studies using the methodological framework will be presented and discussed in Chapter Five. Finally, the implications for the research results are discussed in the conclusion Chapter Six.

CHAPTER FOUR: PROBLEM STATEMENT AND THE METHODOLOGICAL FRAMEWORK PROPOSED

4.1 Introduction

This chapter explains the research investigation process. The rationale and the approach used in this research to study activity process modelling and analysis for fashion and textile innovation is presented. In other words, this chapter addresses the methods used to model and analyse the activity processes: framing the application procedure, framing the data observation and treatment, and framing alternatives and result evaluation. The second section introduces the framework methodology that assists in defining an activity process system, how it is used to represent process characteristics (interactivity relationship and dependencies), how a dependency-based method is used to show the characteristics and how the characteristics may be manipulated to re-structure the processes. Finally, the framework proposed is used to evaluate the innovation activity performance and schedule, and then optimise the expected 'to-market' cycle time using a genetic (inexact) algorithmic search strategy.

In the third section, the types and the method of the data collected in this research are described. This section illustrates how the key process attributes (process sequential precedence, dependency, duration, their respective variances, and likelihood of iteration) and their patterns have to be recorded for use in analysis. A data elicitation technique is presented to access and interpret expert knowledge as judgemental qualitative input data. Finally the implications that the methodology framework provides for managing and modelling global activities are discussed.

4.2 Methodology framework

4.2.1 The issues that the novel framework addresses

As explored in the previous chapters, planning and managing innovation activity workflow faces many challenges and issues, like the indeterminacy of process iteration, interlaced activity interaction among a number of people and enterprise teams that are dispersed and have informal communication systems. The key issues, particularly from the point of modelling and scheduling, are reiterated. The desired features of a novel modelling methodology are developed further.

- Irregularity of information and data interchange among segregated functional and enterprise teams makes the backward process flow likely and inevitable. From an organisation or functional structure perspective, the direction of information processing is not always in line with the activity task structural sequences that have conventionally been employed to model workflow processes and assign resources (Badke-Schaub & Frankenberger, 1999; Cross, 1994; Hammer, 1990).
- Inevitability of process rework due to in-process failure, modification, updating, etc. trigger ripple (chained) effects towards interdependent activities and teams. Such interdependent relationships result in sources of delay, costly process reviews and quicker response (Millson *et al.*, 1992). These undesirable responses are commonly ignored and covered up by additional processes identified in some other, seemingly logical, activities. The extended cycle time is thus undetected.
- Indeterminacy of the optimum process structural model stems from the exponentially increasing evaluation complexity. Objective evaluation and verification of alternative activity process models cannot easily be made at the early stages of business activity planning. As such the performance of activities cannot be guaranteed or correctly reflected by the models, and does not take account of

contingency management for process changes. This is the reason why the majority of activity planning modelling methods are advocated, but not implemented.

- Different types of interactivity dependencies make process sequencing difficult and complex. In most cases, decoupling the interdependent activity process relationships by policies entails the effective flow of information towards the process end goals. However, it is hard to select and justify where dependencies should be decoupled (ignored), either by using process planner intuition or by using advanced computational tools (Falkenauer, 1998; Wall, 1996).
- The magnitude (strength) of an interactivity process dependence that represents the importance of an interaction or information exchange among activities is difficult to measure. In essence, for pairs of activities, interdependencies show how beneficial or how important an earlier activity output is to the input of a following activity. Dependency is variable and changes with time and context; it is polysemous throughout stages of a process cycle. To measure and represent the magnitude in alternative process structure systems requires the assessment of psychometric values, which are themselves very judgemental and unstable from perceptual points of view.

In recognition of the above, we attempt to integrate and mix some of the ideas discussed in the previous chapters for managing and modelling innovation activity processes. These ideas are brought forward to develop a methodological framework in which complex and ill-defined activity process structures can be compared and evaluated in a time-efficient manner. In the coming subsection, a proposed framework that copes with the identified issues is presented and explained.

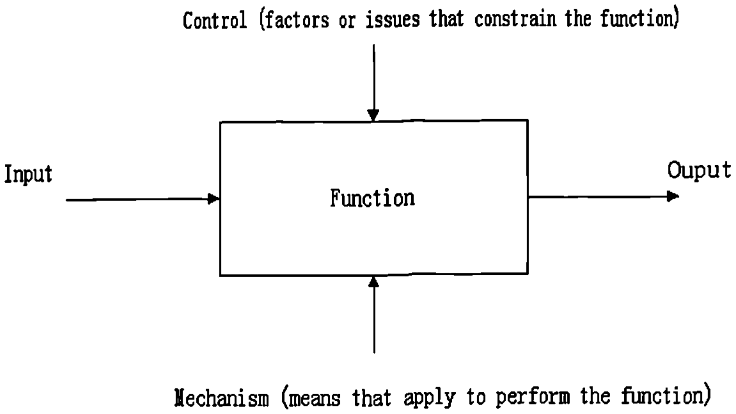
4.2.2 Understanding innovation activity processes

As described in the previous chapters, the innovation process is treated as an integrated activity system comprising sets of concurrent innovation tasks and activities. How it performs stems from early planning, congruous decision making, high autonomy and horizontal interaction at low organisational levels. Adapting integration as the general theme for innovation does require that the innovation process activities are known and analysed carefully at the early stages of innovation projects. It also needs to assess the impact of each activity on the innovation effort and time, interactions and respective interdependencies, and the possible alternative structures of process workflow from which management must select. Therefore, as an essential part of activity process modelling, decomposition of primary activities through which clear-defined process objectives can be achieved is a pre-requisite for the modelling processes. The main purposes of initial activity decomposition include:

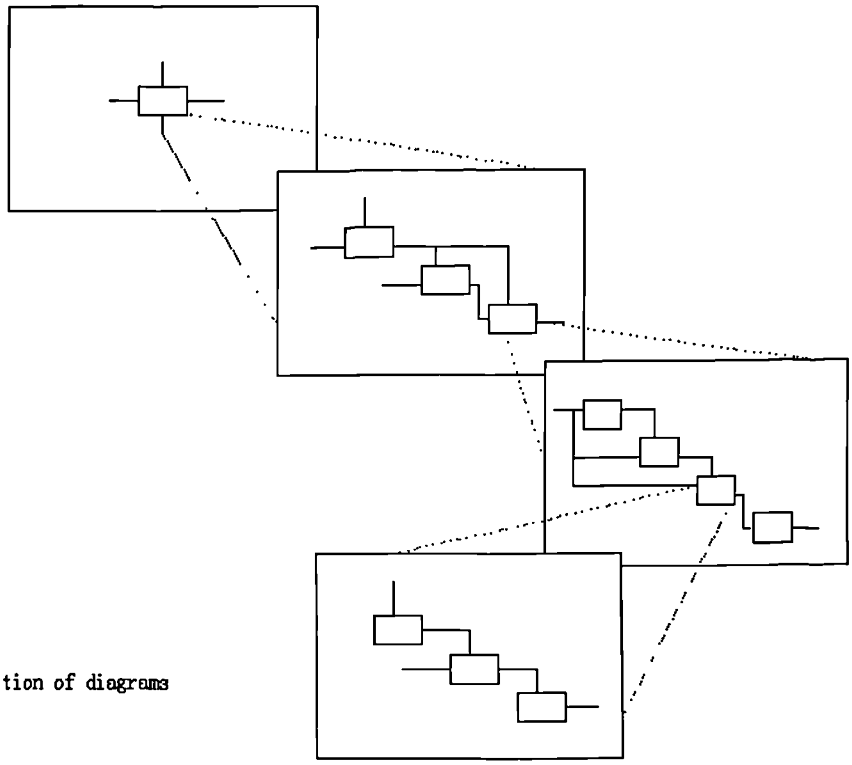
- providing overall knowledge of the existing activity processes and the resource requirements that enable each activity process to start and proceed;
- understanding the essential activity structure that shows the precedence relationships among the activities in order to design and control the flow of information and physical resources;
- avoiding repetitive activities that are hidden in different process activity names and so consume resources without being recognised; and
- depicting an existing process structure that allows the easier estimation of the potential value of process improvement and the costs that may be incurred to achieve the improvement.

4.2.2.1 Decomposition of structural innovation activity processes

In the framework proposed, IDEF0 is adopted to enquire and describe the activity workflow. IDEF0 originates from SADT (Structural Analysis and Design Techniques), an activity modelling technique developed by Ross (1977) based on the information flow process among activities. IDEF0 uses boxes to indicate activity tasks and arrows to denote directions of inputs, outputs, controls and mechanisms of the tasks (see Figure 4-1).



(a) Modelling concepts



(b) Decomposition of diagrams

Figure 4-1 The decomposition of activity process system by IDEF0 modelling techniques

In essence IDEF0 depicts a system of information transformation through a flow process of organised and interdependent activities. The arrows attached to the left side of the boxes indicate input information or objects needed to initiate the process. The inputs are transformed by the activity into so-called output results that are indicated by arrows pointing outward from the right hand side of boxes.

On the top of the boxes, control arrows are connected, representing the relevant constraints to monitor or control the respective activities within boxes. The arrows at the bottom part of boxes denote the mechanisms by which the activities in the boxes are supported or accomplished. An activity can be further decomposed into more detailed sub-activities at subsequent levels. Hence, it is possible to establish an initial workflow sequence comprising only few activities and then to extend the sequence toward more levels of detail forming a systematic top-down linked activity hierarchy.

Though in most complex cases activity tasks and processes are ill-defined at the early stages of process planning and modelling, decomposition of activity structures still assists planners in investigating the process system in a formalised and extendable manner. The approach also aids the documentation of the possible alternative activity structures and their respective performances (Sarkis & Lin, 1994; Hashemipour *et al.*, 1997). This hierarchical activity decomposition gives rise to the following merits:

(1) IDEF0 decomposes and builds an activity system from a top-down perspective, aiding the understanding of information flow among organisational units and enterprise functions at whichever level of detail the model planner intends to consider. It is easy to maintain and document both in written and electronic formats.

(2) Such a hierarchical activity structure is graphically depicted and easily understood intuitively from different functional perspectives. It forms a convenient and effective model for people from all disciplines to communicate and discuss all the aspects of activity structure.

(3) The process flow is based on the way the activities use the input-output information. It shows the precedence relationship that allows a preliminary enquiry about the inter-activity dependencies. The interrelated representation of input-output information, process control and mechanisms enables model planners to see activity systems holistically and to model activity process in a highly integrated manner.

(4) IDEF0 provides a definition of a system's underlying functionality that can be independent of the

current organisational structure. As such, an existing vertically partitioned organisational structure can be re-assessed and redesigned from a process perspective that views overall performance horizontally across vertical individual departmental or enterprise units.

However, because of its simplicity and hierarchy-based representation, IDEF0 does not allow modelling which includes explicitly parallel running activities or for very informal communication and interaction. It does not adapt well to modelling process flow paths and activity process progress that contain significant elements of process iteration or stochastic behaviour of activity processes. Common criticisms of use of the IDEF modelling techniques include its inability to visualise complete systems holistically and the difficulty in representing the structural relationships between different levels of the activity hierarchy. In an attempt to overcome the deficiencies, an alternative method, using relational matrices to denote activity structures, is adopted. The matrix is a relational representation that illustrates structural activities (units) in a square format; activities are listed vertically in roughly chronological order and horizontally in the same order. The elements in the matrix show the types of relationship and precedence among the activities. Researchers in the field have coined the method as Dependency Structure Matrix (DSM) modelling and employed the approach to analyse large scale product development activities (Austin *et al.,* 1999; Browning, 1998a; Eppinger *et al.,* 1994, 1997; Kusiak, 1995; Smith & Morrow 1999; Steward, 1981, 1993; Whitney, 1990 and Yassine, 1998, 1999a, 1999b).

4.2.2.2 Dependency structure matrix (DSM)

In a DSM representation, the activities are structured as a collection of interdependent process tasks in a square matrix. Each receives information and/or resource to proceed the respective activity and consequently passes on the process outputs (information or processed resources) forward to the dependent downstream activities for continuing the processing. See the Figure 4-2. In a simplest DSM model, binary or symbolic values are used to show the activity task interdependencies. The lower diagonal elements refer to the dependencies of forward information flow. The upper diagonal elements refer to the backward dependencies whereby information would be passed backward to upstream activities for modification, revision or rescheduling. A dependency is defined in a non-diagonal element denoting an activity marked in a column, which, upon completing its task, passes output toward the activities marked in the respective row. For example: in Figure 4-2(a), matrix cell (c,f) indicates a backward dependency of process 'c' on the output of process 'f'; the weighting of that dependency is indicated by a numerical, 4 in this particular case. A set of forward dependencies are indicated in the lower diagonal elements. Figure 4-2(b) shows a reordering of the process sequence which has eliminated the backward dependency problem identified in Figure 4-2(a) by positioning activity 'f' before activity 'c'.

For a pair of activities which exhibits both lower and upper diagonal dependency elements, they are interdependent, resulting in problems of process iteration which could seriously affect a number of activities ordered in between them in the sequence. Pairs of activities with no non-diagonal element are independent and can be arranged to proceed concurrently or in any convenient location within the whole sequence. A DSM assists process planners to identify structural problems within a process system and support restructuring, or reordering, of it to improve performance allowed by alternative structures.

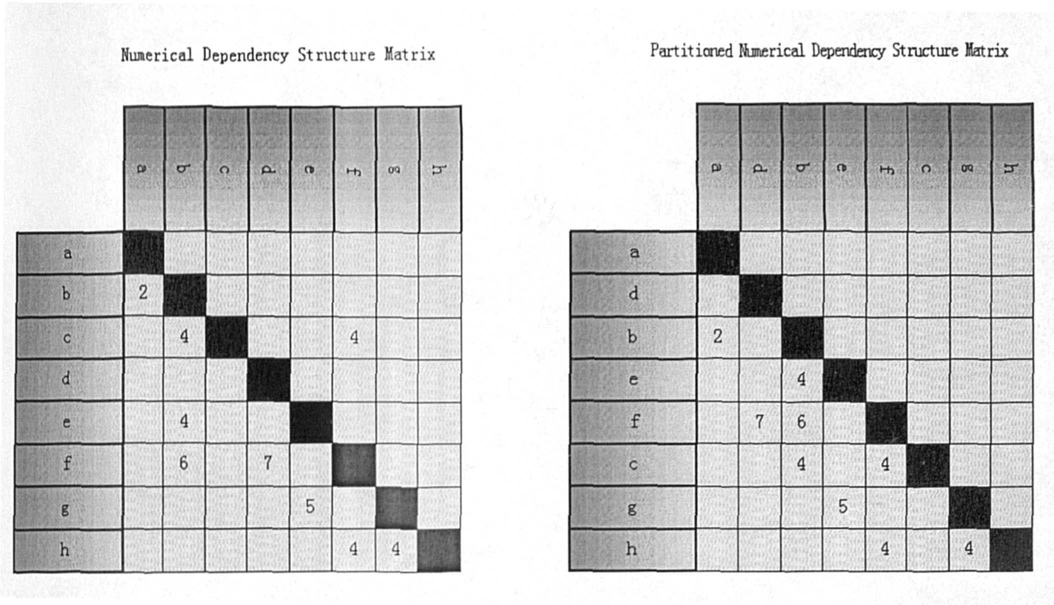


Figure 4-2 Illustration of simple dependency structure matrix models and its manipulation

Researchers have developed several algorithms to cluster and re-sequence activity tasks in a process system to minimise process iteration or to establish the optimum forward process flow (Kusiak, 1995; Smith, 1992; Steward, 1991). The DSM can be modified to represent the dependencies in numerical values showing different degrees of "vitalness" of inputs for downstream activities with respect to the upstream activities providing those inputs. By analogy, the evaluation concepts used in this type of DSM are similar to theoretic network graphs that infer the behaviour of interconnected activities by weighted vertex-and-arc precedence constraints. Kuisak & Wang (1993) use a so-called "triangulation algorithm" to redefine new product features and re-engineer design processes. Smith & Eppinger (1997) used the method to evaluate tendencies to rework due to interactivity dependencies and named their model as a "work-transformation matrix". McCulley & Bloebaum (1996) use such numerical dependencies to represent the inter-compatibility between product components and to quantify the effect of changing a product's parametric value in a particular design task on the other design tasks that depend on the parameter. The dependencies are derived by difference equations among sets of product variables. Concerning human-based DSM, Browning (1998) used numerical dependencies to study the interaction among product development teams and defined interactivity dependencies in terms of a judgemental rating scale for the 'vitalness' of inter-team information processing.

4.2.2.3 Manipulation of process structure and interdependency

As mentioned in Chapter Three, structural analysis is somewhat like a "what-if" game on the cause-effect structural problem, looking for the jujitsu points in the system (Steward, 1981). As we apply the concepts to examine an activity system, the jujitsu point is where we expend the minimum effort to achieve the maximum beneficial effect on the system. Similarly, in DSM modelling, we attempt to describe the structure and find the most critical interdependent activity tasks which, once the relationship is changed, cause the entire activity process to improve significantly. In reality, activity tasks in innovation projects are interrelated and operate non-sequentially. Change any one and all of the rest will be affected. In this subsection we describe how a DSM achieves this purpose and how the examination of dependencies between activities plays the most significant role in DSM manipulation.

4.2.2.3.1 Partitioning Dependency Structure Matrices and re-sequencing the activities

There are many procedures and algorithms to sequence a set of activity task in a DSM. Steward (1981) firstly uses a formal digraph procedure to "chunk" (groups) of strongly interdependent activities into activity blocks; he then exchanges the columns and rows of the activity blocks until the path of the forward process flow is optimised. A block is the largest subgraph in which every vertex in the subgraph has a dependency path to every other vertex in that subgraph; i.e. they are looped. Most research uses the term "partitioning" to describe such an analytic procedure to identify the tasks in individual loops and to cluster them in a block along the DSM diagonal, such that all the preceding tasks of the block appear somewhere before the block (Steward, 1993).

4.2.2.3.2 Tearing Dependency Structure Matrices and decoupling the activities

The next step in manipulating a DSM is to reorganise the activity tasks within an activity block, i.e. altering the relational structure among sub-activities within each block. The simplest way to do so is to "tear" (ignore) one or more feedback marks or values (the upper diagonal elements) within a block such that re-sequencing of these within-block tasks maximises the lower triangular (forward dependencies) of matrix. How to decide which the order of tearing of DSM marks/values (decoupling the interactivity dependencies) is a significant problem. Questions occur with regard to deciding which block(s) should be torn first; on what criteria do we justify the feasibility of tearing interactivity dependency in order to improve the entire system in a desired way? When the system is large and complex, how is a particular tearing sequence justified? It is often found that sets of similar solutions can be provided by entirely different torn structures. These questions are very subtle and are determined by a number of assumptions and policies about which types and strengths of interdependencies should be considered first. Existing literature provides no optimal method to determine the priorities. Yassine *et al.* (1999a) mentions this situation and concludes the following commonly accepted criteria for tearing procedures:

(1) Minimise the number of tears. It follows the theme proposed by Steward's jujitsu approach. For large and complex team-based DSMs, tearing inter-team dependencies implies an approximation or a guess about what may happen after the relationship is decoupled. This approximation is indeed subjective and the performance of the resulting DSM is always uncertain. We therefore prefer to minimise the number of tears.

(2) Confine tears to the smallest block along the diagonal. The logic behind this criterion is that if there are loops within loops, the interaction within inner loops is more frequent and leads to a higher probability of process iteration.

(3) If a DSM is populated by numerical values showing different degrees of interactivity dependency or coupling strength, first tear those marks of the partitioned DSM farthest from diagonal. In most sequencing algorithms, a pair of activities with weaker interdependency tend to be ordered, or

coupled, far from each other and the dependency mark tends to be remote from the matrix diagonal. Tearing weak interactivity dependencies without additional activity restructuring effort is of a lower disruption risk resulting from the interactivity disconnection.

Steward (1981) suggests the use of a so-called "shunt diagram" (to record the frequencies of activities involved and repeated in a circuited flow) to identify the tears that change the systems most significantly. However, this approach is criticised when the number of activities involved in a circuit increases, as the construction of the shunt diagram becomes very problematic. Rogers (1996) uses a heuristic genetic algorithm to search for the optimal ways to tear the interactivity dependencies for NASA's projects. It is claimed to be very sophisticated; unfortunately the method is restricted for use and evaluation outside the U.S.A. The methodology established for this research is also based on a genetic algorithm (GA) to define the possible set of tears, i.e. pairs of activities that are to be decoupled. Since the technical aspects of GAs are not the primary scope of interests in this thesis, the technical statements, pseudocodes and programme header files are described in detail in Appendix A.

In essence, the main goal of tearing is to break information processing loops in an activity block and establish a more feasible execution sequence for the tasks within the block. It is logical that activity tasks that are least dependent on, but provide maximum input information to the rest of dependent tasks within the block should be scheduled to be torn first.

At this point it is important to consider how the values of interdependency are derived so that we are allowed to decide which tearing or decoupling of the interdependent activities should be performed first. This is the most critical issue in the DSM analysis process because we need to know the likely impact that tearing a pair of activities will cause on the whole activity process system. Without clear specifications of different levels of interdependency, we cannot be confident of scheduling which activity interdependency can be chosen as the first to 'truncate'. The next section considers this issue and presents methods that are currently adapted to measure the interdependency. The issue is the crux of the whole DSM structural analysis application and the heart of methodology framework proposed in this research.

4.2.3 Measuring interdependency among organisational teams

4.2.3.1 Existing methods for measuring interdependency

Eppinger *et al.* (1990) used the following three measures to capture the strength of dependency among activities:

- Vitalness of dependent information: if activity B vitally/insignificantly depends on the output of activity A, then activity B is inclined to having a strong/weak dependency on activity A.
- Predictability. Similarly for the pair of activities, A and B, the downstream activity B can confidently predict the input information provided by activity A, activity B tends to be weakly dependent on activity A.
- The rate of information transformation: Suppose activity B is very dependent on frequent interactions with or provision of information from activity A, then the rate of information transfer is high and dependency of activity B on A tends to be strong.

Wang (1995) divides dependency relationships into two extremes, 'soft' and 'hard' dependency. If activity B depends on activity A, but activity B is allowed to start before activity A, the dependency is soft and tends to be weak. Contrarily, if the activity B has to proceed immediately after the completion of activity A, the dependency is hard and strong. The strength of interdependency is then measured in a designated Likert scale from "soft" to "hard". These numerical dependency values are consequently used to represent the relational vitalities in DSM and the corresponding values are weights of importance in the flow graph. Notably, the transformation of DSM into graph modelling and analysis purports to establish a stochastic Markov process. This traces the optimal flow path of the expected process cycle using different cost/objective functions and schedules the order of activities using various coupling dependencies.

Browning (1998a) interprets dependency values as the estimated probability that interdependent activities are likely to be involved in process iteration. Using the probability values, the DSM supports the estimation of the overall project duration and project costs. In an intuitive sense, such a measure of dependency is based on perceptual estimations (by experts) of the chance that an iterative processes would occur. However in most cases, especially for innovation processes, experts do not have adequate information or experience about the nature of novel projects; as a result their judgemental estimation tends to be vague, inconsistent and not reproducible.

Yassine *et al.* (1999a) recognises the problem of polysemic interpretation of the strength of dependencies among interactivity experts and uses an alternative approach to measure interdependencies more accurately. Yassine uses two complementary measures, sensitivity and variability, to assess the interdependencies in a multi-attribute form. Such measures are further converted into a single value of dependency using utility preference theory. For a pair of activities, the sensitivity refers to the scale of how much change in an activity task will occur in response to an alternation in input information provided by the predecessor activities. Again, the variability refers to the possible deviation of an activity output that could occur as a result of receiving new input information. If an activity is incapable of making a good guess about the output of the predecessor activities, the activity is regarded as very dependent on the actual provision of the information; the dependency tends to be strong. Importantly, the interdependency is denoted here by in a composite utility function comprising a number of attribute values, which measure judgemental (conceptual) constructs reliably and consistently. However, Yassine confines the measurement of interactivity dependencies to information-based attributes and does not take into account the source of interdependency arising from organisation factors, such as the strategic sharing of resources, political intervention, level of autonomy, priority and so forth. Modelling workflow processes across organisation activities, which is heavily characterised by intensive human-centric interactions, is more difficult and subject to much more error when accounting for the reality of business activities.

4.2.3.2 A proposed interdependency measure

The methodology we propose in this research is to extend the methods mentioned above and establish a more effective (objective) measure of interdependencies for human centric interaction using multi-attribute utility theory (MAUT).

Utility theory concepts stem from econometric and psychometric measures about personal preference values (Keeney & Raiffa, 1993; Kirkwood, 1997). The concepts are based on the notion that outcomes of objects (policies, products, service, events, etc) can be evaluated in terms of quantified utility or preference values that people expect. Utility of an object is measured on a zero-to-one scale, showing relative preference or "worth" in a range of possible (expected) outcomes of the object. An object may comprise a number of attributes that cannot be directly compared and evaluated through conventional or tangible metrics, like cost vs. time. The magnitudes of different attributes are converted into utility preference values and tradeoffs between different attributes can be evaluated through a common measurement scale . Much of the theory concerns the methods for soliciting and quantifying the 'utility' of various objects or attributes in different specific problems. Formal methods for determining preference data to build utility functions are extensively elucidated by other researchers (Keeney & Raiffa, 1993; Shephard & Kirkwood, 1994; Thurston, 1991) and will not be discussed in this thesis. A fundamental treatment of the representation of multi-attribute utility is annexed at the end of this chapter.

Applying the notion to assessing the inter-activity dependencies, we denote that:

> Interdependency is a function of utility referring to how much 'vitalness' an interactivity relationship has over a range of numerical values which are derived from information provided by the associated activity teams; i.e. interdependencies are derived from a numerical expression for the relative importance/worth of an interrelationship among activities.

Further, the overall interdependency is a composite utility function that comprises two attributes:

> *Vitality* which concerns the attribute of dependency arising from the significance of the dependent information exchanged, $v(d_{vitality})$, and
>
> *Governance* which concerns the attribute of dependency that arises from organisation dependency constraints, $g(d_{governance})$.

$$Interdependency = f\{v(d_{vitality}), g(d_{governance})\}$$

The vitality of dependent information is assessed by a description of four different levels of information significance and emphasises the consequence if the dependent input information changes. Table 4-1 describes this attribute construct extracted from the questionnaire (see the Appendix B) used in this research.

Table 1. Description of input-output information vitality

Attribute levels of vitality, $d_{vitality}$	
3	Absolutely necessary and vital to proceed the activity. Any change will give rise to a large impact on the activity and the whole activity is required to be reworked
2	Commonly useful to support the action and/or refine activity decisions. Any change will demand partial rework in the activity
1	Optional, to verify actions and decisions in the activity. Any change will result in the least impact and you may even decide not to rework or rework with the least effort.
0	Unimportant (no such explicit statement; activities beyond that explicitly stated as above are treated to fall in this level.)

Governance is referred to the dependency arising from some aspects of organisational and political restriction on the process workflow, like personal authority, document formalities, control, rules, policies, autonomy, divisions of job, staff versatility and so on. For a pair of activities, if an activity has to start immediately following the completion of the other activity; or in other words, it is strictly governed by the other activities, the dependency tends to be strong. Contrarily, if this activity is dependent on the other one, but flexibly allowed to start beforehand, then the activity is loosely dependent and governed, i.e. the dependency is weak. For assessing this dependency attribute among activities, a description of four different levels of organisation governance is provided and extracted as in Table 4-2:

Table 4-2. Description of governance dependency

Attribute levels of governance, $d_{governance}$	
3	Strictly not allowed to start until the completion of dependent activity has been formally advised
2	Flexibly allowed to proceed and overlap with the dependent activity upon the receipt of corresponding formal advice.
1	Loosely governed by dependent activity with the least level of formality and official requirements for start of the activity
0	Independent (no explicit statement in questionnaire; activities beyond that explicitly stated as above are treated to fall in this level.)

These two attribute dimensions are not mutually utility-independent and exhibit a certain extent of complementarity. That is to say, the overall interdependency function is expressed in a conditional multiplicative representation form. As the two dependency attributes are assessed directly using respondents' judgemental ratings on the same utility scale, the level of the values of these two attributes can be directly applied to indicate the degrees of interdependency:

$$\text{Overall dependency,} \quad D = (d_{vitaltiy} + 1)(d_{governance} + 1) - 1$$

The resultant interdependency values can have one the following numerical values, 1,2, 3, 5, 7, 8, 11, and 15 where 15 means an extremely vital and binding interactivity relationship and 1 means a zero or trivial interrelationship. Making use of the numerical values, we can populate a DSM's non-diagonal elements with representations of the strengths of interactivity relationships and easily appreciate their precedence. To reiterate, the range of values describing different strength levels of interdependency stem from a notion that the significance of information exchanged and organisation governance constraints co-exist and affect interaction among activities simultaneously.

Other scales of dependency strengths were investigated. It was thought that a longer scale of dependency strength might allow sharper and better discrimination resolution, i.e. using more scale intervals, and that we may therefore more easily observe the "jujitsu" points that, once broken, lead to effective control of undesirable process iteration and activity re-design. Technically this is true, but respondents tended to be less able, or less confident, when asked to distinguish the actual differences between intervals on a longer rating scale for a single conceptual attribute. Ratings for such scale were inclined to be biased towards the centre of the scale and prone to much lower reproducibility.

4.2.4 Activity re-sequencing with a computer-assisted G.A. method

When a mark in a DSM is torn, it means that a relationship between a pair of activities is decoupled (temporarily ignored for examining the restructuring options). As such, behaviour of the whole activity process structure will change. However, we cannot instantly know how much better or worse the result of such change will be. For each test we make by tearing a mark or a set of marks, we restructure the whole set of interrelationships among all activities and re-partition the activities into blocks. The impacts are estimated using a range of objective criteria functions, such as the total process cost or the expected cycle time span. In a very large complex activity system, the evaluation complexity grows exponentially with the increasing number of activities. When we are asked to evaluate what will happen if an uncertain number of marks are torn, we are actually facing a NP-hard question. In technical words, the solution is non-deterministic and cannot be handled by the existing capacity of most computers, even though the tearing procedure in a DSM is guided by values of different interdependency strengths. Facing this issue, researchers (Bloebaum, 1995; Bloebaum *et al.*, 1992; Leu *et al.*, 2001, McCulley & Bloebaum, 1996; Rogers, 1996; Wang, 1995) developed some heuristics to search for optimal solutions for large and complex DSM problems. Heuristic searching requires a series of strategic procedures or rules aimed at finding a nearly-optimal solution(s) within a level of acceptable confidence. Solutions may be inexactly optimal, but comparatively "good enough". Among advanced heuristic methods, genetic algorithms (GAs), are regarded as the most effective and convenient to apply. A GA refers to any search process simulating the natural evolutionary process (Falkenauer, 1998; Goldberg, 1989; Michalewicz & Fogel, 2000).

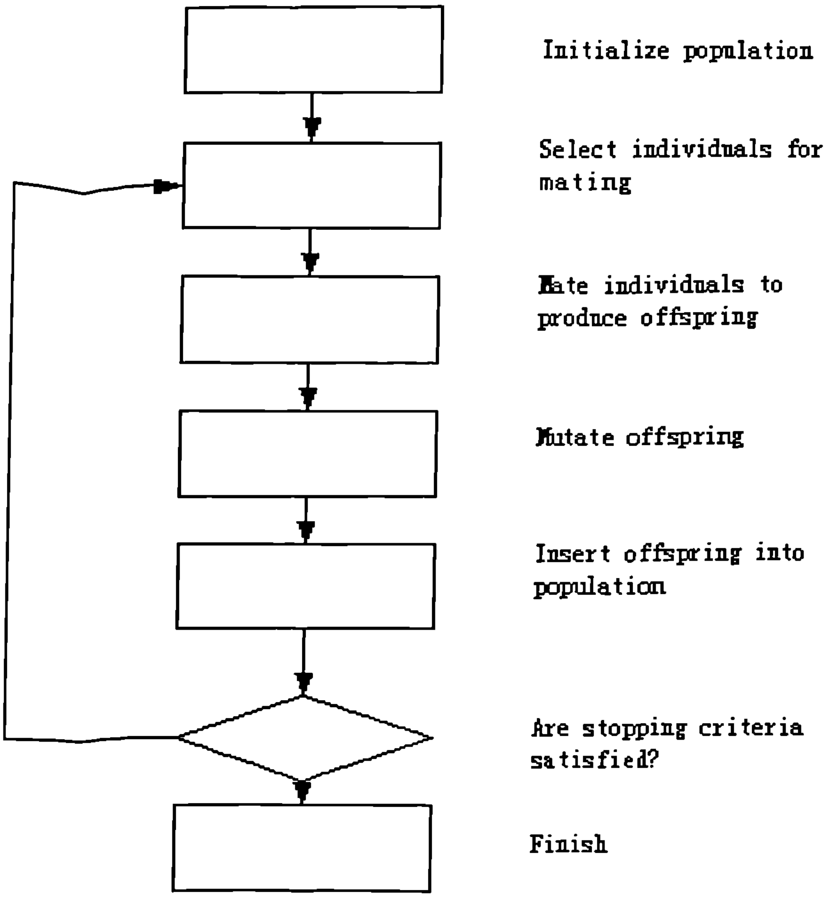
In this investigation, a genetic algorithm (GA) was developed in an attempt to support the search and provide advice about the expected consequences for a combination set of "approved" marks in DSM which are allowed to be torn randomly. Approved marks are those marks which have a level of interdependency strength lower than a specified threshold value. Succinctly, a DSM is restructured into a directed graph representing the precedence and flow of activity processes. Activities are denoted by vertices and the interactivity dependencies are denoted by the directed arcs (links). Then the GA generates a given number of possible transformations such that the initial graph structure is changed by severing an arbitrary number of arcs. The possible alternative structures of activity flow are then compared and evaluated to find a feasible process structure that yields the minimum expected activity process cycle time or cost.

4.2.4.1 Search procedure of genetic algorithms

In the initial stage of applying commonly used GAs, a population representing a set of possibly feasible solutions, will be initialised and sorted to find a set of "best-fit" individuals (solutions). The gene structures (chromosome) of these individuals are changed through two essential GA operators, crossover and mutation. These operations give birth to the next generation of the solution population. Again the best-fit individuals are sorted out and allowed to crossover further and mutate. After a number of generations, the near-optimal solution set evolves. In the DSM GA analysis developed in this investigation, the chromosome of population individuals is characterised by different DSM interdependency structures. Initially, an assigned size of population pool is generated by randomly decoupling the interactivity relationships within designated levels of interdependency strength.

Individuals carrying different chromosomes in terms of DSM interdependency structure are evaluated through Monte-Carlo simulation about the expected time spans for completing the whole activity process. The evaluation implies the fitness of individuals allowed to "survive" and "mate" in coming generations; in other words, a DSM interdependency structure entailing shorter expected cycle time will be more likely to be selected and retained for next generation population pools. The likeliness is algorithmically assigned. As such the most 'fit' (appropriate) individuals are selected, forming a pool of individual mating parents. Then, a controlled proportion of the parents are mated and undergo crossover to produce new children, i.e. DSM interdependency structures between two random individuals are correspondingly truncated and exchanged so that a new interdependency structure is created. During this process, a small controllable sized set of individuals are allowed to mutate chromosomes. The purpose of this is to delay the time of solution convergence and to avoid possible best-fit solutions from falling into local optima too quickly.

In our methodology, we use a steady-state GA or an overlapping population evolution method. This means that, in each generation, a portion of the population is replaced by the newly produced children that carry 'best-fit' chromosomes, forming a steady size of population in each generation. After a number of generations showing the expected activity process cycle time spans converging into a stable value, the GA stops and lists the feasible suggestion of tears of DSM marks. The GA is a tool to enable the efficient evaluation of a DSM under different tearing (decoupling) policies. For instance, we can choose a decoupling policy to transform an assigned number of randomly selected interdependent relationships into either mutually independent ones or sequentially dependent ones. Alternatively, we can also choose a decoupling policy that specifies level of interdependency at which a pair of activities are allowed to be decoupled. Moreover, we can always specify the maximum possible number of interdependent activity pairs to be allowed to decouple. Figure 4-3 illustrates the genetic algorithm procedure to search for heuristically feasible solutions.



Extracted from Wall (1996)

Figure 4-3 Diagram for a steady-state GA search procedure

4.2.4.2 Rationalising an optimal *interdependency structure in the GA evaluation*

The interdependencies among activities are denoted in directed network graphs. Activities are represented in numbered vertices and relational dependencies are in arcs, or edges. For specific pairs of activities, arcs starting only from lower numbered vertices and pointing at higher numbered vertices are regarded as having sequentially forward dependency. That is to say, downstream activities are dependent on upstream activities. Contrarily, arcs starting from higher numbered vertices pointing backward to lower numbered vertices are backward links indicating the notion of backward dependency. Such relationship carries various degrees of probability of process iteration initiating from downstream work processes. Pairs of vertices showing no arc mean that the activities are mutually independent. Such activities can be run in parallel, without the constraint of a sequencing order. For vertices linked by both forward and backward arcs, circuits exist and imply significant interdependency. For such a pair of activities, these arcs form a loop, in which one activity is dependent on the other, i.e. implying iterative workflow process. Once an activity fails or calls for iteration, the other one should re-start simultaneously. In the cases modelled, the arcs carry various degrees of dependence strength, giving different priorities for restructuring the interdependency structure. The objective of the GA evaluation is to find an expected minimum activity process cycle time from a set of feasible activity process paths through decoupling different forms of interactivity dependency, i.e. removing backward arcs to control inter-activity iteration or removing both interdependent arcs for activities to proceed in parallel.

To support the selection and change of different GA parameters in the DSM analysis, a GA tool was developed and coded in C++ to run on a Windows platform. The tool supports automatic checking of input data integrity, result documentation and diagnosis of parameter specification problems. The algorithmic statement, pseudocodes and the corresponding header files are appended at the end of this thesis. The detailed programming coding of the GA are not included in the thesis discussions.

In brief, the GA rationalises an activity process model as follows:

(1) The process goes through a structured sequence of activities and incurs some uncertain process iteration due to interactivity dependency, i.e. the process path exhibits a certain degree of stochastic Markov's behaviour. The model can be represented as in transition graph. The process time of a sequence structure is determined by an expected (average) time span of the repeated process cycles.

(2) The alternative process times are the result of changes in the relational structure among the

activities. In a process system, the time can be reduced by decoupling interdependent activities so that they are mutually independent, or breaking the backward process flow between activities to control the uncertainty of the process extension caused by iteration; using transition graph terminology, the looped circuits are unwrapped and cut.

(3) The connected activities that are available for change are determined by the degree of strength of interdependency between pairs of activities. Those activities whose interdependency strength tends to be weak are scheduled to change with higher priority. The GA has to be given a level of interdependency strength as an activity restructuring policy to proceed with the decoupling.

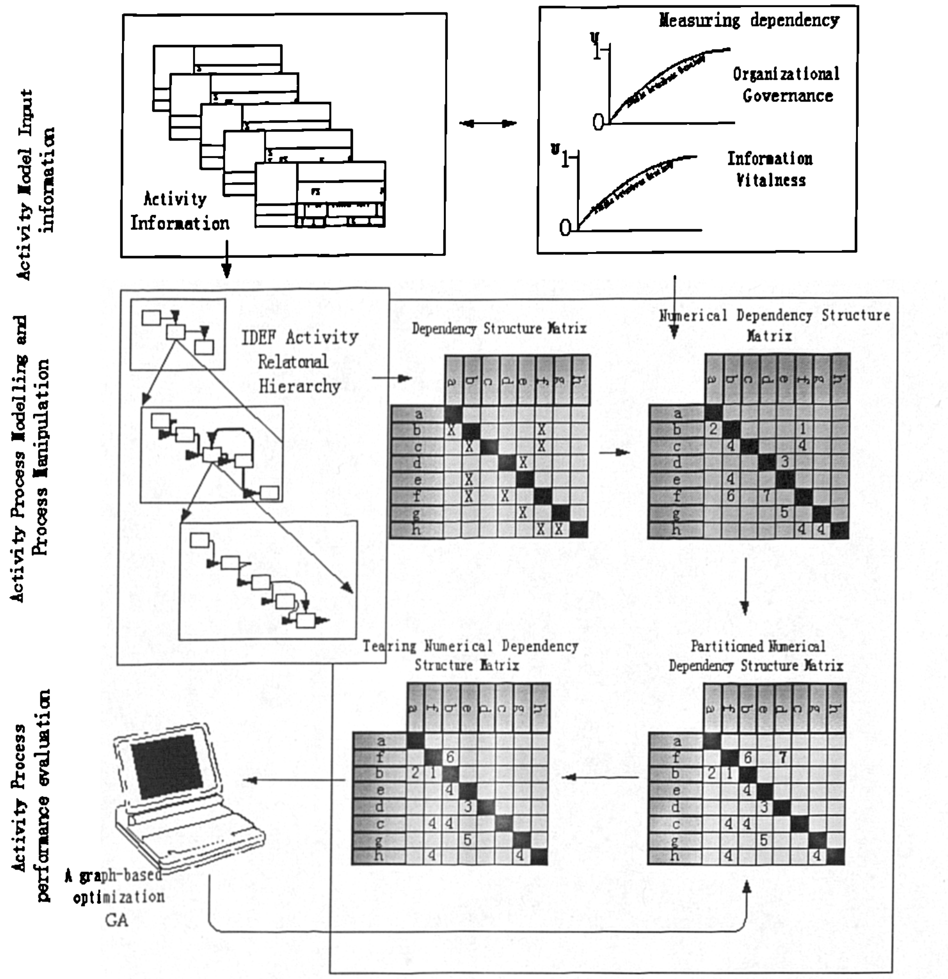
(4) In a process system, the extent of re-structuring is determined by how many interdependent activity pairs are allowed to change. Again, this is another restructuring policy given as a GA evaluation input. Combined with (3), it means that we should specify the maximum number of possible interdependent activity pairs and the possible levels of interdependency strength for the GA to deal with.

(5) Given a set of interdependent activity pairs, the selection of appropriate pairs for decoupling is a combination problem. The GA provides a search strategy to "converge" a nearly optimal, but computationally cost-conscious suggestion.

(6) Once an activity is called for iteration, its dependent activities are also required to re-start concurrently. As the process of iteration is dynamic and uncertain, a multiple number of iterations are possible, but should be constrained. In reality innovation activities are time driven, not allowing activity tasks to repeat uncontrollably, even though the in-process activity results are inadequate, or not perfectly satisfactory. Therefore a learning function is imposed for activities to reduce (decay) their duration in subsequently repeated processing. The process learning restricts the number of activity iterations and forces the iterative process to stop at some point.

(7) Evaluation is based on the Monte-Carlo process in improvement of time. The models are developed in the form of alternative activity structures of interdependency that represent redesigned

innovation processes and create restructured relations of innovation teams.



The Proposed Methodological Framework

Figure 4-4 The methodology framework proposed in this research

Figure 4-4 summarises the procedure of the methodology framework proposed in this thesis. As illustrated, the methodology comprises three implementation stages, namely: (i) activity model input information, (ii) activity process modelling and process manipulation and (iii) activity process performance evaluation. In the first stage of developing model input information, process activities are investigated and defined structurally. The interactivity dependencies are specified and measured. The corresponding activity properties, e.g. duration, probability for iteration, etc are recorded. The second stage is to build visual models to represent relational structures of the activity process and provide executable inputs that will be evaluated by the GA in the last framework stage.

The methodology framework proposed is to model alternatives of potentially feasible activity structures and the respective workflow sequences. Very often, we question how we can make use of the DSM-based frameworks as a kind of practical management tool to manage activity processes. Different researchers have different suggestions: Steward (1981) suggests to "massage" the matrix. It means that, once the matrix is built and re-sequenced, the cause and effect relations that occur in the matrices are displayed: we can then see the structure of the entire system more clearly and can make knowledge-based changes to the original inputs and resources that pass from one activity to another activity. The inputs or resources that are essentially the same may be combined, and irrelevant ones eliminated. This reduces the size of the DSM and makes it easier to understand. A reduced DSM can be further "massaged" and the activity system relations can be clarified further; as they become clearer it is likely that other changes will follow.

Yassine *et al.* (1999a) extends this type of discussion to risk management being equivalent to tearing interdependency marks in a DSM. In his conclusion, he suggests that using the strength of interactivity dependency we can infer the potential impact or penalty that decoupling an interdependent relationship (tearing the respective mark in the DSM) would bring. Three managerial actions can be taken into consideration for eliminating DSM marks, comprising (i) straightforward elimination, (ii) overlapping or re-defining the activities and (iii) collocation of interdependent activities. When the strength of interdependency between a pair of activities is classified as very weak, the activity relationship can be decoupled so that they can be run concurrently without paying an extraordinary penalty for the change. When the strength is moderate, tearing the mark in its DSM means the activities are redefined to change their interaction patterns. Clark & Fujimoto (1991) propose to overlap this kind of activity. That is, activities are managed by splitting the work into sub-activities and increasing the frequency of interaction for information exchange, making them overlap within a specified time period, or releasing them from the competition of similar resources. When an extremely significant interdependency is broken, we suffer very seriously from the discontinuity of workflow progress. To avoid this, we can collocate the activities together, either by means of geographical transfer of whole teams or virtual (information technology) systems.

The proposed framework as applied to managing interdependent activity process systems has been described. However, we have not yet seen the demonstration of the use of the framework or discussed its implication for managing globally dispersed innovation activities. This discussion follows in Chapter Five. Using two implementation cases we shall thoroughly explain how the framework applies to real life businesses and to what extent the framework can contribute.

4.3 How to proceed the framework

4.3.1. Data observation (expert knowledge capture) and questionnaire design

Given a complete set of well-defined activities and tasks, it should be relatively straightforward to collect the data, build the models and do the subsequent analyses required to establish an improved activity workflow sequence and schedule. However, this is not very often the case. Very interestingly, it found that respondents, who may know all sorts of information about the resources and conditions required to proceed their own activities, may not be certain about who or which downstream activities will receive the results of completed activities; such persons may also not know how vital the information is to the downstream activities. Because of these issues, during the design of questionnaires, we required respondents to define their predecessors, as, knowing these for each activity task, it is logical to trace the successor activities by inverting the orders of the activity tasks.

Very often, surveying data for modelling activity processes is not a matter of statistics. There are only a few persons who can provide information and data about the detailed structures of activity process flow for existing or novel activity projects. The data collected from these persons is not easily validated or proved through some objective indices or procedures. Such kind of expert knowledge can only be captured through a very careful procedure to maintain a high level of data quality and consistency (Shephard & Kirkwood, 1994). The questionnaires (see the appended sample of questionnaires) in our research attempted to adopt a structured elicitation method and to reinforce the experts' reasoning about the questions and allow self-verification of their knowledge and expertise. The questionnaires used in the framework comprised four elicitation stages: (1) motivation, (2) structuring, (3) conditioning and (4) verification.

Stage 1 - motivation, helped experts to determine the scope and purpose of the questionnaires and was aimed at and encouraging respondents to think carefully about their responses. A conceptual picture was used to illustrate contextual aspects for managing activity workflow processes. Furthermore, experts were asked to briefly describe the activities for which they were responsible. This was found to be motivating for them to prepare data/information that was to be asked for at the later stage of providing activity precedence and interdependency information.

Stage 2 - structuring, meant that questionnaires were specifically designed to elicit a great amount of interlaced activity data piece by piece in an orderly manner (See Part B of the appended questionnaire). Instead of asking people to rate on a scale both the vitality and governance of a pre-listed dependent activities simultaneously, questionnaires requested the data in two subsequent steps: firstly they categorised interdependent activities in terms of the four categories related to different levels of vitality; and secondly, they rated the governance of the respective interdependent activities identified in the first step, and eventually identified and rated any other activity not previously identified. Such structuring of the type and volume of data requested was to ensure the desired levels of adequacy and thoroughness of the data that the experts endeavoured to provide.

Stage 3 - conditioning, was used to allow experts to further think about the process data that they had provided using additional and relevant questions that demanded specific answers. At this elicitation stage, experts might contemplate any contradiction or discrepancy against the previous information given and so enable them to adjust their responses where necessary.

Stage 4 - verification, contained similarly formatted questions that asked for data supplementary to the earlier questions on precedence and interdependency. The purpose of this was to elicit respondents to re-verify what they had already provided in the questionnaires. Therefore responding to the whole questionnaire document takes a certain amount of time and effort. A facilitator was necessary to support the experts.

In addition, we may question the level of detail required to define activity task for modelling activity systems, or whether a set of detailed operational tasks should be wrapped up as one activity task. These questions are actually very subtle in modelling activity systems. The finer the detail in defining the tasks, the greater the effort required to collect and analyse the data, but the greater are the benefits to be derived from the analysis (Checkland, 1999; Steward, 1981). One approach to working with large or novel systems is to first define a small number of general activities for a thorough preliminary analysis. On this basis, the activities analysed are then extended or decomposed into more detailed levels of inquiry. That is, a top-down approach should be allowed to capture data in different levels of detail. This explains why the IDEF0 functional activity models was adopted to represent and analyse such kind of data requirements.

4.3.2 Data assumption and interpretation

This subsection discusses a very subtle issue in measuring utility-based interdependencies. In the framework, an interdependency strength is a two-dimension utility construct, comprising information on vitality and organisation governance. In utility theories, one of the fundamental concepts of multi-attribute utilities theory is that of utility independence. Its role in multi-attribute utility theory is similar to that of probabilistic independence in multivariate probability theory (Keeney, 1974; von Neumann & Morgenstern, 1947). We do not discuss the theoretic properties here. Utility independence is important because it greatly simplifies analysis of utility-based measurements. Various shapes of single utility curves are derived independently with respect to the one another. If a dependent relationship exists between two single utility functions, the overall (composite) utility function will change and tends to be unstable. That is why, it may be problematic for Yassine *et al.* (1999a) to measure two single attributes that are closely associated with the interpretation of importance for use in processing information; i.e. they are closely utility-dependent. The multiplicative representation of "worth" of interdependency will be unstable. It is a necessary and sufficient assumption in the questionnaires that respondents are required to perceive and rate the two single utilities independently.

4.3.3 Recapitulation of the procedure

Here we reiterate the proposed methodology to proceed modelling of activity process system as follows:

(1) Define the essential goals of an activity process.

(2) Decompose the activity process into a set of corresponding process functional requirements which are in turn used to identify the activities that specifically deal with individual functional requirements.

(3) Review the nature of information and resources that the activities require to proceed. Trace the transfer of the information and resources to show the crucial activity workflow processes. It can enable us to have a preliminary understanding about the relational structure of these activities.

(4) Organise the activities using IDEF0 decomposition models. The activities are represented in a

hierarchical format and, in most cases, associated with the documents or information systems that are used in the activities. In due course, we may need to choose the experts concerned to verify the representation of the IDEF0 activity models. Correspondingly, transform the IDEF0 into a DSM to allow an overview of the entire interdependent activity system.

(5) Define the conditions we aim to achieve as a consequence of changing the process structure. The conditions include the demand for a shorter activity process cycle, restrained resources for existing activities, the control of uncertainty and so on.

(6) Invite experts capable of understanding these conditions to provide information. Discuss the conditions and conclude the objectives of improvement for the existing activity processes.

(7) Get the experts to list the scope and aims of activities for which they are responsible and to describe how they communicate with the others, both from the information processing and organisational requirement perspectives.

(8) Convert the data collected in (7) into different patterns and strengths of inter-activity dependency. The DSM can be populated by the numerical values of dependency.

(9) Reorder the rows and the corresponding columns of the DSM to show the alternative structures of the system more clearly. The re-ordering is done using the methods of partitioning and tearing discussed in Section #2. Alternative tearing of the DSM are then suggested and modelled through the GA evaluation.

(10) Look for changes we may make to the system and use the DSM to help evaluate the most promising of the newly developed activity structures.

(11) Choose the best course of action from the alternatives.

4.4 Concluding remarks: Implications

Using the framework to build and analyse the large scale and complex activity process models underlies some interesting implications, which include:

(1) The framework acts as a knowledge base. The models built by the framework are based on interactivity information flow and organisational aspects governing the interactivity dependency. That is, the organisation wide communication should be taken into account and planned. It suggests more opportunities of team participation and collaborative interaction, during the progress of the process or after the completion of it. Knowledge builds on a holistic systems thinking approach and forms a vital base for all parties of an organisation to be prepared for and be committed to change in response to contingent market environment requirements.

(2) The framework acts as management tool. The framework reflects the nature of team interaction among interdependent activities. Interdependency leads to the issues of process iteration. It may be due to inefficiency of sharing the same information and resources, or due to ineffectiveness of activity definition. The framework provides an analytic and diagnostic procedure to manipulate the interdependency among organisational activities and teams.

(3) The framework acts as a design tool. To model the workflow processes, we are allowed to consider and design corresponding facilities or the human resources that are required to support the processes. From engineering perspectives, the framework plans, schedules and changes activity projects better and more agilely. To design globally dispersed activity processes, such kinds of framework become very critical for successful activity integration and co-ordination. Today's virtual enterprise or manufacturing concepts are involved in *such strategic planning*.

Annexe: The multilinear form of two attributes (dimensions) is :

$$u(x, y\} = u(x, y\_0) + u(y, x\_0) + ku(x, y\_0)u(y, x\_0) \quad or,$$

$$u\{x, y\} = 1/K\{[K\, k_x u(x,y\_0) + 1][K\, k_y u(y, x\_0) + 1] - 1\}$$

where

(1) $u(x, y\_0)$ is conditional utility functions of $u(x)$ normalised by $u(y) = 0$

(2) $u(y, x\_0)$ is conditional utility functions of $u(y)$ normalised by $u(x) = 0$

(3) k_x and k_y are assessed single attribute scaling constants

(4) $1 + K = (1 + K\, k_x)\,(1 + K\, k_y)$

(5) The overall interdependency values ensure that

$$u(x\__{0,}\, y\__0) = 0 \text{ and } u(x\__{1,}\, y\__1) = 1$$

Extending the form into a multi-attribute utility function

$$U = 1/K\,\{\Pi_i[\,1 + K\, k_i\, u_i\,(x_i)] - 1\}$$

And (4) becomes $1 + K = \Pi_i\,(1 + Kk_i)$

Also

if $\Sigma_i k_i > 1$, then $-1 < K < 0$

if $\Sigma_i k_i < 1$, then $K > 0$

if $\Sigma_i k_i = 1$, then $K = 0$ and

the utility function in multiplicative form reduces to an additive form:

$$U = \Sigma_i = k_i u_i(x_i)$$

CHAPTER FIVE: CASE STUDIES: ILLUSTRATION OF THE FRAMEWORK MANAGING AND MODELLING INNOVATION ACTIVITY PROCESSES

5.0 Preamble

This chapter describes how the dependency-based methodology described in the previous chapter is used in modelling and re-designing the innovation activity processes for the global fashion and textile marketplaces. Two case studies are reported and used to illustrate:

- How the structure of critical business activities can be identified and represented using the dependency-based modelling methodology in the context of the innovation process for global marketplaces, characterised by intensive information exchange in non-hierarchy network patterns and a high level of process uncertainty (non-scheduled stochastic iteration);
- How the innovation performance is altered by the changes of interdependency among globally dispersed innovation teams from the perspectives of the information and organisation management.

At the early stage of innovation, organisation team interactions are often frequent, informal and non-scheduled. The effectiveness of interaction is largely determined by how well the teams in different activities are co-ordinated collaboratively and how these interdependent activities are designed and structured coherently. In the case studies, some of the interactivity process dependencies are restructured and subtly re-defined, using the proposed methodology, to facilitate efficient process progress throughout all stages of the business cycles. Pragmatically, it furnishes a more effective process modelling tool for an industry that is not accustomed to global process planning from a methodological design viewpoint. The activity process modelling and evaluation in the cases studied is considered to be representative of many other business processes dealing with global marketplaces. By focusing effective modelling and analytic effort on the process interdependency, the management strives for disciplined and integrated innovation processes.

5.1. Introduction

The research involves two studies: The first study concerns the case of managing and scheduling a novel treatment system development in an international silk manufacturing enterprise. The silk enterprise possesses direct investment in silk sericulture, material processing and finishing, and garment manufacturing in China and Far Eastern countries. It has also established its owned wholesale and retail offices in Western countries. The study involved in this company stems from an attempt to introduce novel processing methods for textile products that can satisfy future manufacturing and environmental requirements. In the course of the research, the enterprise was evaluating a novel finishing method through the use of a plasma treatment on silk and other textile products. The second study concerns the case in an international fashion buying company which was attempting to model and establish activity systems that could manage the existing product development operations more flexibly and responsively according to changing market requirements. Though the product development teams are globally dispersed, they are required to work collaboratively to maintain an integrated world-wide product image, cost structure and quality. In this study, the buying company takes a role at the process interface, supporting global retail distribution, consolidating and monitoring the affiliated companies, and integrating the whole manufacturing operation along its supply pipelines. In these two case studies, the companies provided the observations, illustrating the use of dependency-based activity modelling methodology to generate major improvement in the innovation processes.

In the coming sections, the discussion is organised as follows:

- in Section #2, the case study for the silk enterprise is presented. The background of developing a new silk treatment process is initially described, illustrating the contextual issues in managing a technology-centric innovation project which mainly concerns engineering process rather than product features. Making use of the methodology approach of this research, it is shown how the enterprise gains benefit from modelling the embedded interrelations among system development activities.

- Then in Section #3, the methodology is applied to an international apparel buying company. The case observation actually generalises the scope of the crucial activities involved to develop mass customised fashion products in very short cycle times. It also illustrates the peculiar contextual issues that indirectly determine choice of proper co-ordination mechanisms which are required to manage the progress of the process among interdependent activities. Through the analysis of the cases, the impact of change of process interdependency on process performance is examined. Finally, the validity and managerial implications of the methodology are discussed and the issues for modelling and managing complex projects for innovation are addressed.

5.2. Innovative treatment processes in silk fashion

5.2.1. Industrial motivation

This study was motivated by one of the Strategic Development projects of the Institute of Textiles and Clothing in Hong Kong. One of the project's objectives was to study the feasibility of using advanced technologies for coping with present and future textile industry challenges. Such challenges mainly result from the increasing awareness of environment health and safety, demand for faster production processes, rising pressure due to increasing energy and processing costs, capricious customer requirements to end-product performance, and increasing uncertainty in managing global operations. One of the approaches entailed better management to develop and design a textile processing method that was highly flexible, environmentally conscious and cost-effective. Such motivation initiated the study of plasma treatments, especially for protein-type textile products. In an effort to investigate efficiently and to evaluate such novel processing systems, the project team was testing novel techniques that could aid scheduling and managing the investigation processes. At the same time, they could significantly reduce the uncertainty in the final stages of system implementation and effectively predict the investigation results. As such the methodology framework proposed in this thesis was adopted to model and manage the investigation processes. In the project, a Hong Kong-based international silk enterprise* participated and provided specific processing requirement data for establishing the target process performance.

In this case, the enterprise was attempting to adopt an advanced system that could improve its existing performance in the wet finishing and dyeing production processes, in relation to the cost, lead time and environmental concerns. One of the feasible technologies was an implementation of novel plasma applications in processing silk and silk blend textiles. Research using high energy glow discharge to improve finishing performance had already gained significant results, but making it available for mass production was still subject to additional research, engineering inputs and technical evaluation. So far this type of industrial technology was limited to that provided by Japan and Italy. An Italian company, Viero, had developed vacuum-based plasma treatment technology. An atmospheric system was anticipated to be ready for industrial use in the near future. The project team and the silk enterprise were committed to analysing the feasibility of using the technology and integrating it into the existing production plants.

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* The enterprise participates and contributes to the other on-going parts of Areas of Strategic Development project

The silk enterprise which participated in this study is well known for silk processing and silk fashion garment supply in international markets. The enterprise sources raw silk in Hangzhou, one of the biggest silk trade bases in China. Finished or semi-finished silk yarns and fabric are further processed in the Delta Region of the Pearl River in the southern part of China. The office in Hong Kong mainly accounts for the sale and merchandising services and the co-ordination of the dispersed manufacturing activities in the Far East region. Its subsidiary overseas offices in New York, Amsterdam and London are correspondingly responsible for taking care of its retail store clients and a certain limited amount of distribution of their registered brands. In the course of investigating the feasibility of this novel technology, the project team faced some very challenging issues; these included the problems of how to integrate information between the dispersed activities, identifying which activity information should be taken into consideration and which could be neglected, and furthermore, what methods for information transfer were needed. A thorough process planning and modelling seemed necessary.

In the following sections, the concepts of plasma treatments are outlined in respect to its applications in the textile industry. The issues in managing this novel system design and its evaluation are discussed. Finally the proposed modelling methodology is applied to managing the development processes; it is shown that the development activities are improved through changing the interactivity dependency.

5.2.2 What is plasma treatment?

A plasma (or glow discharge) is a partially ionised gas with near equal densities of positive and negative charges. It can exist over an extremely wide range of temperatures and pressures. The solar corona, a lightening bolt, a flame and a neon sign are all examples of plasma-type discharges; in these applications the result is to produce light. However, for plasma treatment of textiles, an extreme physical and chemical environment is needed. Glow discharge plasma can be generally realised under vacuum using

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and requests to keep their identity anonymous in this thesis.

the energy from an electromagnetic field; the energy is transferred from the field mainly to the plasma electrons. The collisions between energised electrons and the gas molecules lead to the generation of ions, free radicals, UV radiation and new kinds of active chemicals. These charged particles impact on the surface of materials and cause modification. Vacuum, between 20 and 200 Pa, is necessary to keep the temperature of the plasma below 50^0C. In general, the basic external control parameters of a plasma treatment system include the initial gas composition, gas pressure and flow rate, discharge current and treatment time. Figure 5-1 describes the principles of the plasma treatment and the respective system component design.

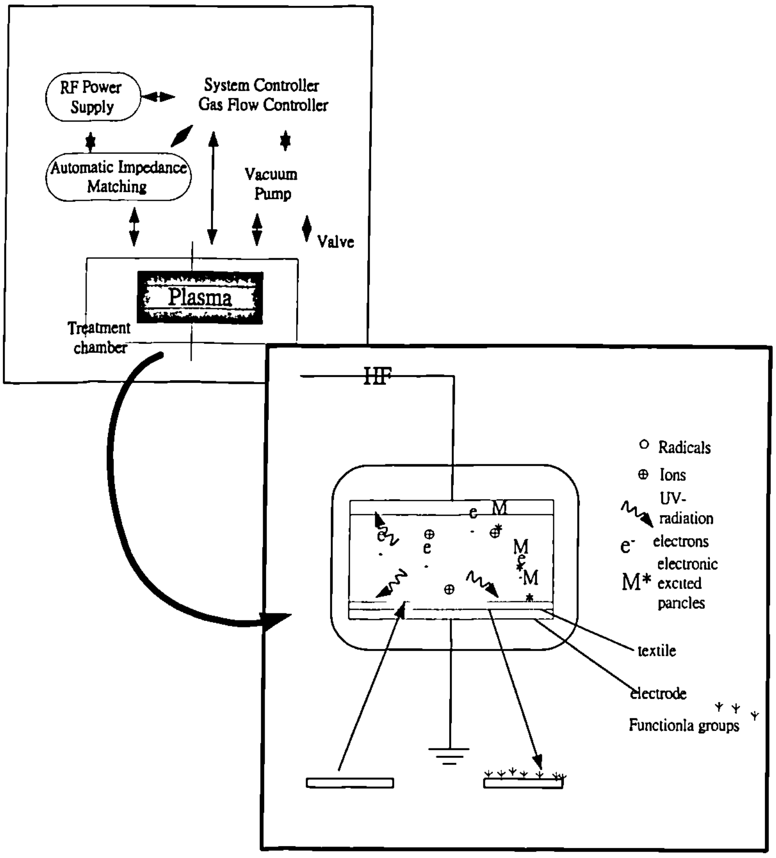


Figure 5-1 A notional plasma treatment process on textile materials

(sourced from Vohrer, 1997)

According to requirements, the materials to be processed will be treated for some seconds or minutes with a plasma. Experimental observations show the following improvement results:

1. Cleaning effect: this is mainly combined with changes in wettability and surface texture. The consequential effects lead to plasma treated silk having better dye affinity, fastness, brilliance of hue and printed effect.
2. Increasing micro-roughness. This results in an anti-pilling finishing for wool, silk and other protein type textiles. It significantly increases the adhesion forces of bonded fabrics and coatings.
3. Generation of radicals. The presence of free radicals induces secondary reactions like cross-linking, graft polymerisation and reaction with oxygen to generate hydrophilic surfaces. Better hydrophilic properties allow effective dye-uptake in a lower temperature environment.

From the industrial viewpoints, treatment of plasma provides a number of additional merits, which include:

- High applicability and lower consumption of chemicals. It can be applied to almost all textile materials to increase wettability, adhesion, antistatic and surface smoothing properties.
- Etching effect. It optimises the textile surface properties without alteration of the basic characteristics of the textile.
- Environmentally friendly. The process is performed in a dry and closed system, and excels in high reliability and safety. Some types of pollution problems can be better controlled.

In spite of the known advantages, plasma technology in industry-scale applications is not yet common. The problem may arise from difficulties of integrating plasma reactors into processing systems alongside conventional machines. In addition, the design of high-speed continuous plasma systems is another crucial problem. Such detailed investigation of parametric characteristics of this technology and engineering is outside the scope of this research; instead, the focus is on how the initial activities of the investigation are managed as an innovation process using the modelling framework.

To integrate a plasma treatment process into an existing processing system requires re-evaluation of the entire finishing processes and the parametric requirements. The feasibility of such a novel system is determined by the opportunity benefits (savings) gained from the use of plasma against all the costs incurred to change the configuration of interdependent processing machines. Different experts and technical teams are required to work out these changes and estimate all possible ripple impacts on the areas, e.g. staff training, plant layout redesign, re-configuration of power and utility supply, control systems and in-plant traffic systems.

Due to the complexity of the system, communication and co-ordination amongst the departments, engineers and designers was extremely challenging; very often, contingency meetings were called for repeatedly discussing unresolved problems. Teams and experts spent a great deal of time and effort in processing and distributing investigation information. The situation was even more complicated as, during the course of the investigation, system requirements often had to be changed and updated to meet dynamic requirements from the markets. Succinctly, we observed that the challenges encountered in the silk enterprise were generic and common to many organisations that managed innovation activities.

5.2.3 The activity processes taken into consideration for system redesign

Silk finishing passes through several process stages, including degumming or partial scouring, weighting, bleaching, dyeing or printing and finishing. The detailed parametric processing requirements in each stage are determined by a number of end-product specifications that conform to the overall expected standards and qualities. These parametric settings are inherently interrelated, both within and across the processing stages. At the outset of investigating and designing a plasma-enhanced process system, the project and engineering teams collaboratively conceptualised the basic system configurations and the potential effect of plasma treatment in each of these chained process stages. Through a series of brain-storming discussions, the system design concepts were screened and examined, and eventually a nearly feasible concept was chosen. This proposal concept was then examined in more detail, with the goal of having enough information to prepare an installation specification that entailed accurate examination of the system's compatibility and operational performance among processing system components. During the early course of the innovation project, three project managers from the silk enterprise and the chief research investigator from the HK Polytechnic University responded to the process profile questionnaires. To maintain the data consistency and adequacy, they were requested to examine the data provided by the other contributors and verify it as necessary. The investigation process was indeed iterative and involved repeated efforts for information updating and design revision. Teams frequently reminded themselves that they needed to consider all the other aspects of implementation, like power and water supply, control and diagnosis system, plant layout and facility set-up, staff training, continuity of material flow between processing system components. Table 5-1 lists the crucial innovation stages identified and the respective activities.

Table 5.1 Activities for Plasma Treatment Investigation

	Innovation stages	Activities (document/information process-based)
1	A1 Determine parametric treatment requirements	A11 Determine treatment effects on types of textile patterns and features
2		A12 Determine optimal treatment conditions
3		A13 Develop a database for treatment process control
4	A2 Determine effects with other wet and finishing processes	A21 Evaluate effects on softening sericin and degumming processes
5		A22 Evaluate bleaching and weighting
6		A23 Determine dyeing and printing processes
7		A231 Evaluate and select dyes for dyeing and printing
8		A232 Determine fixation and steaming processes
9		A24 Evaluate washing processes
10	A3Engineer processing system and changes	A31 Design the plasma reacting system
11		A32 Redesign processing machinery
12		A321 Redesign wet processing machinery set-up & conditions
13		A322 Redesign printing process set-up & conditions
14		A33 Design water and gas supply system
15		A34 Design electric supply system
16		A35 Design waste control system

17		A36 Design plant control system
18		A37 Design plant layout and facilities
19	A4 Design production information system	
20	A5 Develop human resource training programmes	
21	A6 Develop inspection metrics and procedures	
22	A7 Evaluate overall system performance and economic feasibility	A71 Estimate environmental impact
23		A72 Analyse judgmental preference of the investment
24		A73 Analyse rate of return

5.2.4 Representation of the process interdependency and DSM modelling

Table 5-2 shows the list of activities included in the plasma treatment feasibility study project. For each activity the numbers of successors are indicated. Successors are the other activities, which are dependent on the particular activity, due to the vitalness of its output information and/or the restrictiveness of organisation governance. These two measures are indicated by the numbers in brackets following the respective successor activities.

Figure 5-2a shows the corresponding 22-activity dependency structure matrix, but illustrating the dependency attributes which resulted only from information vitality among the activities. Each row and its corresponding column represent an activity task and the off-diagonal numerical numbers are the measured precedence and strength of interactivity dependency. Figure 5.2b shows the re-ordered (partitioned) rows and columns, which helped us to understand more about the dependency structure from the original relational structure. The techniques to re-sequence the activities have been described in Chapter Four. The re-sequencing process is not considered here, but we must know how to interpret it and use it to illustrate how and where our framework can contribute to a more meaningful model for managing interdependent activities.

Table 5-2: Plasma treatment activities and their interdependency measures

	Activities (document/information process-based)	Successors ($d_{vitality}$, $d_{governance}$)
A11	Determine treatment effects on types of textile patterns and features	A12(3,0), A13(3,1)
A12	Determine optimal treatment conditions	A11(3,0), A13 (3,1)
A13	Develop a database for treatment process control	A11(3,1) , A12(3,1), A31(3,2), A4(3,2)
A21	Evaluate effects on softening sericin and degumming processes	A22(3,0), A231(2,0), A24(1,0), A321(3,2), A322(3,2)
A22	Evaluate bleaching and weighting	A21(3,0), A231(3,0), A232(1,0), A321(1,2), A322(1,2)
A231	Evaluate and select dye and print stuff	A21(2,0), A22(3,0), A232(2,0), A24(2,0), A321(2,2), A33(2,1)
A232	Determine fixation and steaming processes	A231(2,0), A24(2,0), A33(2,1), A34(1,1)
A24	Evaluate washing processes	A22(1,0), A232(2,0), A33(3,2), A34(1,1)
A31	Design the plasma reacting system	A321(3,1), A322(3,1), A34(3,2), A36(3,2), A37(3,3), A5(3,3), A71(1,3), A72(2,3), A73(2,3)
A321	Redesign wet processing machinery set-up & conditions	A231(2,2), A322(3,0), A33(3,2), A34(3,2), A36(3,2), A37(2,3), A73(2,3)
A322	Redesign printing process set-up & conditions	A321(3,0), A33(3,2), A36(3,2), A37(3,2), A73(2,3)
A33	Design water and gas supply system	A321(3,2), A322(3,2), A36(3,3), A37(3,3), A5(2,2), A73(3,3)
A34	Design electric supply system	A36(3,3), A37(2,2),A73(3,3)
A35	Design waste control system	A36(3,3), A37(2,3), A71(3,3)
A36	Design plant control system	A37(1,1), A4(2,3), A5(2,2)
A37	Design plant layout and facilities	A321(2,3), A322(3,2), A33(3,3), A34(3,2),A35(2,200), A72(1,3), A73(2,2)
A4	Design production information system	A13(2,2), A36(2,3), A5(1,3),A72(1,2), A73(3,3)
A5	Develop human resource training programmes	A6(1,3), A72(1,3)
A6	Develop inspection metrics and procedures	nil
A71	Estimate environmental impact	A31(1,3), A35(2,3), A72(1,3)
A72	Analyse judgmental preference of the investment	A5(1,3), A71(1,3)
A73	Analyse rate of return	nil

#1

Items	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1! Determine Treatment Effects	1	3	3																			
2! Determine Optimal Treatment Conditions	3	2	3																			
3! Develop A Database For Treatment Process Control	3	3	3														2					
4! Evaluate Effects On Softening Sericin And Degumming Process				4	3	2																
5! Evaluate Bleaching And Weighting				3	5	3		1														
6! Evaluate And Select Dye And Print Stuff				2	3	6	2			2												
7! Determine Fixation And Steaming Processes					1	2	7	2														
8! Evaluate Washing Processes				1		2	2	8														
9! Design the plasma reacting system			3						9											1		
10! Redesign Wet Processing Machinery Setup And Conditions				3	1	2			3	10	3	3				2						
11! Redesign Printing Process Setup - Conditions				3	1				3	3	11	3				3						
12! Design Water And Gas Supply System						1	2	3		3	3	12				3						
13! Design Electric Supply System							1	1	3	3			13			3						
14! Design Waste Control System														14		2				2		
15! Design Plant Control System									3	3	3	3	3	3	15		2					
16! Design Site Layout And Facilities									3	2	3	3	2	2	1	16						
17! Design Production Information System			3												2		17					
18! Develop Humna Resource Training Program									3			2			2		1	18			1	
19! Develop Inspection Metric And Procedures																		1	19			
20! Estimate Environmental Impact									1					3						20	1	
21! Analyze Judgemental Preference Of The Investment									2							1	1	1		1	21	
22! Anslyze Rate Of Return									2	2	2	3	3			2	3					22

Figure 5-2 a The notional plasma-treated process investigation: matrix #1, the initial DSM populated by input-output information vitality values

#2

Items	1	2	3	4	5	6	7	8	14	9	17	20	10	11	12	16	13	15	18	21	19	22
1! Determine Treatment Effects	1	3	3																			
2! Determine Optimal Treatment Conditions	3	2	3																			
3! Develop A Database For Treatment Process Control	3	3	3								2											
4! Evaluate Effects On Softening Sericin And Degumming Process				4	3	2																
5! Evaluate Bleaching And Weighting				3	5	3		1														
6! Evaluate And Select Dye And Print Stuff				2	3	6	2						2									
7! Determine Fixation And Steaming Processes					1	2	7	2														
8! Evaluate Washing Processes				1		2	2	8														
14! Design Waste Control System									14			2				2						
9! Design the plasma reacting system			3							9		1										
17! Design Production Information System			3								17							2				
20! Estimate Environmental Impact									3	1		20								1		
10! Redesign Wet Processing Machinery Setup And Conditions				3	1	2				3			10	3	3	2						
11! Redesign Printing Process Setup - Conditions				3	1					3			3	11	3	3						
12! Design Water And Gas Supply System						1	2	3					3	3	12	3						
16! Design Site Layout And Facilities									2	3			2	3	3	16	2	1				
13! Design Electric Supply System							1	1		3			3			3	13					
15! Design Plant Control System									3	3	2		3	3	3		3	15				
18! Develop Humna Resource Training Program										3	1				2			2	18	1		
21! Analyze Judgemental Preference Of The Investment										2	1	1				1			1	21		
19! Develop Inspection Metric And Procedures																			1		19	
22! Anslyze Rate Of Return										2	3		2	2	3	2	3					22

Figure 5-2 b The notional plasma-treated process investigation: matrix #2, the partitioned DSM from matrix #1

To reiterate, the matrices in Figure 5-2a,b are based on the interdependency arising from use of interrelated activity information. The larger the numerical number, the stronger is the inter-activity dependency. The inner blocks on the diagonal show the sets of activities such that each activity in a block directly affects and is affected by every other activity in the same block. Furthermore, every activity within a large block has a repercussive effect on every other one in the block. Though the activity system consists only of 22 key investigation activities and forms few distinctive activity groups (blocks), we still have the problem of scheduling them so that the activity process can be effectively managed to progress forward without significantly being affected by backward process iteration. The need to adopt an iterative process in order to obtain an optimum solution for the DSMs is valid; in this case study the investigation teams had to consider a novel plasma treatment technology with unknown performance. It reflects a common situation in which decisions are affected by uncertain information and opinion exchange. All of the activities in the entire system are interrelated; a change in any one, and all of the rest will be affected.

If we continue to work on such a matrix structure, for instance we tear all the major backward dependency marks (17-3), (10-6), (16-14) and (15-17) from matrix # 2 shown in Figure 5-2b, the resulting matrix is shown in matrix #3 in Figure 5-3. We can see that the sequence of the activities has not changed significantly or provided significant improvement in terms of activity sequence re-structuring. This explains the motivation behind the research work of Yassine *et al.* (1999a) and Eppinger *et al.* (1990) who attempted to model interdependency in multi-dimensional constructs, to make the dependency scale more sensitive and applicable, and hence distinguish more detailed levels of perceived dependency values.

#3

Items	1	2	3	4	5	6	7	8	17	14	20	9	10	11	12	16	13	21	15	18	19	22
1! Determine Treatment Effects	1	3	3																			
2! Determine Optimal Treatment Conditions	3	2	3																			
3! Develop A Database For Treatment Process Control	3	3	3																			
4! Evaluate Effects On Softening Sericin And Degumming Process				4	3	2																
5! Evaluate Bleaching And Weighting				3	5	3		1														
6! Evaluate And Select Dye And Print Stuff				2	3	6	2															
7! Determine Fixation And Steaming Processes					1	2	7	2														
8! Evaluate Washing Processes				1		2	2	8														
17! Design Production Information System			3						17													
14! Design Waste Control System										14	2											
20! Estimate Environmental Impact										3	20	1						1				
9! Design the plasma reacting system			3								1	9										
10! Redesign Wet Processing Machinery Setup And Conditions				3	1	2						3	10	3	3	2						
11! Redesign Printing Process Setup - Conditions				3	1							3	3	11	3	3						
12! Design Water And Gas Supply System						1	2	3					3	3	12	3						
16! Design Site Layout And Facilities										2		3	2	3	3	16	2		1			
13! Design Electric Supply System							1	1				3	3			3	13					
21! Analyze Judgemental Preference Of The Investment									1		1	2				1		21		1		
15! Design Plant Control System									2	3		3	3	3	3		3		15			
18! Develop Humna Resource Training Program									1			3			2			1	2	18		
19! Develop Inspection Metric And Procedures																				1	19	
22! Anslyze Rate Of Return									3			2	2	2	3	2	3					22

Figure 5-3 The notional plasma-treated process investigation: matrix #3, tearing of feedback marks from matrix #2

Following the framework developed in this research, we use an alternative interactivity dependency construct that is composed of the two attributes, the information vitality and the organisational governance. Though the plasma treatment innovation process is mainly driven by technical input-output information exchange, the activities are still controlled by people under certain policy restrictions which affect the activity interaction. They include the controlled use of shared resources and facilities, policy-restrained work ordering, perpetual review of work progress from superordinates, authoritative intervention, and so on. As such, apart from information flow, these controls become additional sources of dependency from organisational perspectives, restricting dependent activities to start at some points of time after the corresponding preceding activity is initiated. By this means, we use a composite utility value combining the two attribute measures to show the strength of dependency as proposed in our DSM framework.

#4

Items	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1! Determine Treatment Effects	1	3	7																			
2! Determine Optimal Treatment Conditions	3	2	7																			
3! Develop A Database For Treatment Process Control	7	7	3														8					
4! Evaluate Effects On Softening Sericin And Degumming Process				4	3	2																
5! Evaluate Bleaching And Weighting				3	5	3		1														
6! Evaluate And Select Dye And Print Stuff				2	3	6	2			8												
7! Determine Fixation And Steaming Processes					1	2	7	2														
8! Evaluate Washing Processes				1		2	2	8														
9! Design the plasma reacting system			11						9											7		
10! Redesign Wet Processing Machinery Setup And Conditions				11	5	8			7	10	3	11				11						
11! Redesign Printing Process Setup - Conditions				11	5				7	3	11	11				11						
12! Design Water And Gas Supply System						5	5	11		11	11	12				15						
13! Design Electric Supply System							3	3	11	11			13			8						
14! Design Waste Control System														14		11				11		
15! Design Plant Control System									11	11	11	15	15	8	15		11					
16! Design Site Layout And Facilities									15	11	11	15	8	11	3	16						
17! Design Production Information System			11												11		17					
18! Develop Humna Resource Training Program									15			8			8		5	18			7	
19! Develop Inspection Metric And Procedures																		7	19			
20! Estimate Environmental Impact									7					15						20	7	
21! Analyze Judgemental Preference Of The Investment									11							7	5	7		7	21	
22! Anslyze Rate Of Return									11	11	11	15	15			8	15					22

Figure 5-4 a The notional plasma treatment process investigation: matrix #4, DSM populated by composite dependency utility function values

#5

Items	7	8	4	5	1	2	3	6	9	10	11	12	16	14	20	13	15	17	18	21	19	22
7! Determine Fixation And Steaming Processes	7	2		1				2														
8! Evaluate Washing Processes	2	8	1					2														
4! Evaluate Effects On Softening Sericin And Degumming Process			4	3				2														
5! Evaluate Bleaching And Weighting		1	3	5				3														
1! Determine Treatment Effects					1	3	7															
2! Determine Optimal Treatment Conditions					3	2	7															
3! Develop A Database For Treatment Process Control					7	7	3											8				
6! Evaluate And Select Dye And Print Stuff	2		2	3				6		8												
9! Design the plasma reacting system							11		9						7							
10! Redesign Wet Processing Machinery Setup And Conditions			11	5				8	7	10	3	11	11									
11! Redesign Printing Process Setup - Conditions			11	5					7	3	11	11	11									
12! Design Water And Gas Supply System	5	11						5		11	11	12	15									
16! Design Site Layout And Facilities									15	11	11	15	16	11		8	3					
14! Design Waste Control System													11	14	11							
20! Estimate Environmental Impact									7					15	20					7		
13! Design Electric Supply System	3	3							11	11			8			13						
15! Design Plant Control System									11	11	11	15		8		15	15	11				
17! Design Production Information System							11										11	17				
18! Develop Humna Resource Training Program									15			8					8	5	18	7		
21! Analyze Judgemental Preference Of The Investment									11				7		7			5	7	21		
19! Develop Inspection Metric And Procedures																			7		19	
22! Anslyze Rate Of Return									11	11	11	15	8			15		15				22

Figure 5-4 b The notional plasma treatment process investigation: matrix #5, the partitioned DSM from matrix #4

Figures 5-4a, b show the matrices populated by the numbers denoting multiplicative values of the two dependency attribute measures that have already been listed in Table 5-2. In matrix # 4, the strength of dependency between pairs of activities is more clearly discerned. Matrix #5 is the partitioned dependency structure. Interestingly, all the activity blocks are developed within a larger activity block, forming a circuit-within-circuit pattern with the relatively stronger interdependent activities centring at the diagonal. To restructure the whole activity process with least effort, we have to be more concerned with those part activities, as they are 'intensively' prone to iterate.

The matrix #5 contains the element {17,3}, which implies that 17 (design production information system) directly affects 3 (develop a database for treatment process control) and indirectly all the other activities scheduled in between them. Once iterations occur, all the others are adversely influenced. Now we deliberately delete this mark and restrict the backward work process from 17 to 3, giving a matrix #6 as shown in Figure 5-5a. Similarly, the element {20,9} indicating backward process flow from activity 20 (estimate environmental impact) to 9 (design the plasma reacting system) is subsequently deleted from matrix #6, resulting in a new activity structure matrix #7.

#6

Items	1	2	3	7	8	4	5	9	6	10	11	12	16	14	20	13	21	15	17	18	19	22
1! Determine Treatment Effects	1	3	7																			
2! Determine Optimal Treatment Conditions	3	2	7																			
3! Develop A Database For Treatment Process Control	7	7	3																			
7! Determine Fixation And Steaming Processes				7	2		1		2													
8! Evaluate Washing Processes				2	8	1			2													
4! Evaluate Effects On Softening Sericin And Degumming Process						4	3		2													
5! Evaluate Bleaching And Weighting					1	3	5		3													
9! Design the plasma reacting system			11					9							7							
6! Evaluate And Select Dye And Print Stuff				2		2	3		6	8												
10! Redesign Wet Processing Machinery Setup And Conditions						11	5	7	8	10	3	11	11									
11! Redesign Printing Process Setup - Conditions						11	5	7		3	11	11	11									
12! Design Water And Gas Supply System				5	11				5	11	11	12	15									
16! Design Site Layout And Facilities								15		11	11	15	16	11		8		3				
14! Design Waste Control System													11	14	11							
20! Estimate Environmental Impact								7						15	20		7					
13! Design Electric Supply System				3	3			11		11			8			13						
21! Analyze Judgemental Preference Of The Investment								11					7		7		21		5	7		
15! Design Plant Control System								11		11	11	15		8		15		15	11			
17! Design Production Information System			11															11	17			
18! Develop Humna Resource Training Program								15				8					7	8	5	18		
19! Develop Inspection Metric And Procedures																				7	19	
22! Anslyze Rate Of Return								11		11	11	15	8			15			15			22

Figure 5-5 a The notional plasma treatment process investigation: matrix #6, decoupling of backward process dependency between activity 17 and 3 from matrix #5

#7

Items	1	2	3	9	7	8	4	5	6	10	11	12	16	14	20	13	21	15	17	18	19	22
1! Determine Treatment Effects	1	3	7																			
2! Determine Optimal Treatment Conditions	3	2	7																			
3! Develop A Database For Treatment Process Control	7	7	3																			
9! Design the plasma reacting system			11	9																		
7! Determine Fixation And Steaming Processes					7	2		1	2													
8! Evaluate Washing Processes					2	8	1		2													
4! Evaluate Effects On Softening Sericin And Degumming Process							4	3	2													
5! Evaluate Bleaching And Weighting						1	3	5	3													
6! Evaluate And Select Dye And Print Stuff					2		2	3	6	8												
10! Redesign Wet Processing Machinery Setup And Conditions				7			11	5	8	10	3	11	11									
11! Redesign Printing Process Setup - Conditions				7			11	5		3	11	11	11									
12! Design Water And Gas Supply System					5	11			5	11	11	12	15									
16! Design Site Layout And Facilities				15						11	11	15	16	11		8		3				
14! Design Waste Control System													11	14	11							
20! Estimate Environmental Impact				7									15		20		7					
13! Design Electric Supply System				11	3	3				11			8			13						
21! Analyze Judgemental Preference Of The Investment				11									7		7		21		5	7		
15! Design Plant Control System				11						11	11	15		8		15		15	11			
17! Design Production Information System			11															11	17			
18! Develop Humna Resource Training Program				15								8					7	8	5	18		
19! Develop Inspection Metric And Procedures																				7	19	
22! Anslyze Rate Of Return				11						11	11	15	8			15			15			22

'igure 5-5 b The notional plasma treatment process investigation: matrix #7, partitioned DSM with further decoupling of backward process dependency between activity 20 and

We can also consider a number of possible changes between activities as well as the activities themselves. In matrix #7, the plasma activities can firstly be put into two distinctive groups running in parallel with each other. The closely interdependent activities, 1(determine treatment effects), 2(determine treatment conditions) and 3(develop a database for treatment process control) can be combined into a single virtual activity task. Similarly, activity 10, 11, 12 and 16 can be reduced and handled by one group of experts. As such the matrix can be simplified and this allows an improved appreciation of the effects of further change in subsequent matrix manipulations.

However, when the number of the activities grows, "massaging" a large DSM becomes very tedious and the results are also less easily appreciated. This is simply because the way that we select those marks that are to be torn is very judgmental and depends on how much we know about the models and how well we understand the specific case to which the model is applied. The above DSM manipulation can be termed as interpretative structural analysis that examines the activity structure mainly on the connectivity basis. When the analysis is associated with other process performance criteria, particularly the cycle time span and variance, such an interpretative approach needs to be extended.

Considering the above issue, we need a more effective way for anticipating the consequences of changing a DSM structure. In this research, a complementary GA tool was developed to search and evaluate the changed structure in terms of the extent to which process cycle time was improved. In essence, the GA heuristically proposes alternative dependency structures of an activity process with optimal process cycle times, so that we can make decisions and anticipate the possible impacts propagated from changes to its structural dependency. Table 5-3 shows the surveyed data of the expected durations and the possible chance of iteration for individual activities in the plasma investigation.

Table 5-3. The Duration and iteration probability of the plasma investigation innovation process

	Expected time consumed (1/2weeks)	Anticipated iteration Probability
Determine treatment effects on types of textile patterns and features	14	0.6
Determine optimal treatment conditions	14	0.6
Develop a database for treatment process control	10	0.4
Evaluate effects on softening sericin and degumming processes	2	0.5
Evaluate bleaching and weighting	2	0.5
Evaluate and select dye and print stuff	2	0.6
Determine fixation and steaming processes	1	0.6
Evaluate washing processes	1	0.3
Design the plasma reacting system	14	0.85
Redesign wet processing machinery set-up & conditions	3	0.5
Redesign printing process set-up & conditions	3	0.5
Design water supply system	8	0.6
Design electric supply system	5	0.3
Design waste control system	4	0.3
Design plant control system	4	0.5
Design site layout & facilities	7	0.8
Design production information system	6	0.6
Develop human resource training programmes	4	0.2
Develop inspection metrics and procedures	4	0.2
Estimate environmental impact	2	0.4
Analyse judgmental preference of the investment	1	0.2
Analyse rate of return	2	0.4

The GA was aimed at identifying a DSM structure that predicts the shortest time span to proceed the 22 innovation activities. Briefly reiterated, the GA will arbitrarily create an assigned pool of individual DSMs carrying various structural interactivity dependencies, forming the first generation of parents' genes. A proportion of these individuals then undergo two controlled GA operations, crossover and mutation to transform their genes; in other words, crossover is to exchange part of the structure of the activity sequence and interdependency between two initial DSMs; mutation is to, by chance, make an individual gene structure change by itself. The evolved gene structures representing various DSMs generated are then evaluated with fitness functions. In our GA the fitness function is determined by the expected process time span. A given proportion of these best performing individuals are allowed to stay in the pool and the weak ones are screened out. Such an evolution process is continuously repeated until it converges on an optimal DSM with shortest time span. For a given DSM structure, we estimate the cycle time span by using a Monte-Carlo simulation process that takes the average values of a number of process lead times that are generated by varying iteration behaviour in a dependency structure (Goldberg, 1989; Hammersley & Handscomb, 1965). Again the theoretic aspects of Monte-Carlo simulation and GA operations are outside the primary scope of our research interests. All the details of the algorithmic statement and codes are shown in Appendix A.

At the outset of GA evaluation, we have to specify a set of parameters such as the possible levels of decoupled dependency strengths, the maximum possible number of interdependent activity links, the proportion of the population to be included in a crossover, the rate of mutation and the nature of interdependency changes (deletion of interdependent interaction or backward interaction). We refer to such a parameter specification as a 'decoupling policy'. For each evaluation the GA is bound, by a decoupling policy in order to deal with the dependency structure changes. The GA will arbitrarily choose and decouple pairs of activity interdependencies. The performance of the decoupled interdependency structures will be evaluated by the respective cycle time spans. Because of the iterative nature of activity progress, the process cycle time varies stochastically. Therefore, for each decoupled interdependency structure, the GA obtains an expected time span by taking the average of a number of repeated simulation results. After a series of generations of GA evolution, a nearly-optimal solution is identified and indicated as a set of suggested interdependency changes. Table 5-4 extracts some results of GA evaluation with respect to the plasma treatment innovation activities.

Table 5-4 Results of GA evaluation with respect to the plasma investigation activity process

Maximum number of interdependency arc to be decoupled	Maximum level of interdependency strength to be decoupled	Expected cycle time in 1/2week	The corresponding activity pairs proposed by the GA to be decoupled (the backward dependency is removed)
10	15	31	(2,1) (3,1) (3,2) (11,10) (12,10) (12,11) (16,12) (16,13) (16,11) (20,9)
10	8	34	(2,1) (3,1) (3,2) (6,5) (7,6) (8,7) (11,10) (16,13) (20,9)
10	5	54	(2,1) (3,2) (6,4) (7,6)
5	15	35	(2,1) (3,1) (3,2) (16,13) (20,9)
5	8	35	(2,1) (3,1) (3,2) (16,13) (20,9)
5	5	54	(3,2) (6,4) (6,5) (8,7) (11,10)

For a given maximum number of pairs of interdependent activities and possible levels of decoupled interdependency strength, the GA searches for the 'nearly optimal' activity structure and shows the corresponding activity pairs proposed for removal. As such we are given hints to better management of the activity interaction and for further redesign of the innovation activity processes. For instance the backward dependency between activity pairs of (2,1), (3,1), (3,2), (16,13) and (20,19) are found to be the most critical for reducing the activity process cycle time in almost all evaluations. We can suggest adopting a phases-and-gates approach to establish appropriate points of perpetual progress reviews, whereby activity processes are managed strictly to proceed as far forward as possible.

Genetic algorithms provide convenient and cost-effective search tools for finding optimal solutions in large and NP-hard problems. The plasma treatment innovation process only consists of 22 important activities, but illustrates a good example of the use of the methodology framework. The next section presents a case study concerning the much larger scale problem of global innovation activities and how the framework again contributes to managing and modelling interdependent processes.

5.3 Process re-design for global fashion product development activities

5.3.1 Introduction and motivation

In an effort to co-ordinate and consolidate a large number of global activity and communication processes while maintaining regional responsiveness and autonomy, many international fashion distributors and buying companies are trying various novel methods and tools to help them to manage global activities from the perspectives of organisational integration. One such effort is to plan and model the process system holistically so that the information and opinion at all levels of enterprises can be shared, discussed and revised effectively and collaboratively at the early phase of product conception and embodiment, and so that changes in the later stages of production and distribution be minimised. On such premises, the planning and modelling of the processes should be based on an approach that emphasises integrative and effective process sequencing among the interacting activities. Extant theoretic concepts in managing new product development processes that employ activity process flow modelling paradigms and perspectives gives rise to the achievement of several goals:

- To identify how and when information is provided to a point in an activity process, such that the process can be executed sufficiently and completed as scheduled.
- To ensure a high level of accuracy and concurrency for activity interaction and responsive identification of the essential attributes of 'winning' products at the last possible moment within the course of new product development. Such winning products are highly desirable in markets and best meet the changing customer requirements;
- To schedule short life cycle products to markets in a timely manner so that the profit potential of new products and market uncertainty can be adequately anticipated;
- To aid in sequencing activity processes that contain iterations so that undesirable information revision and review can be avoided and controlled, and also so that the costly product change at the later production stages can be anticipated and managed;
- To provide a compact and highly transparent representation of the interactivity process

interaction or communication. Using such a representation, teams and facilities can be easily managed and consolidated more resourcefully and responsively;

- To generate a descriptive model of the whole activity system that provides a prescription for continuing organisational learning and improvement in project management.

In this second case study, we used these concepts to research an international fashion and textiles buying company that was aiming at utilising new methods for improving the process planning and co-ordination of their global activities. At the initial research stage, the company discussed the issues they faced in planning and organising the activities for new product development. A key issue that they raised was the problem of intractable interactions among a large number of interdependent activities that made communication difficult to manage. Very often, information, after passing through a number of subsequent activities, was detected and recognised as inadequate, incorrect or highly uncertain. It forced product development teams to call for upstream activity processes to re-examine and adjust the information. This was attributed to the fact that no single team or enterprise was able to perceive all the perspectives throughout all phases of a product life cycle and anticipate all the possible influences from external environmental market factors.

To illustrate the significance of this in the global fashion businesses, the company cited a common example that marketing teams capriciously asked design teams to revise the design of new products in the upstream processes in anticipation of probable changes in market demand or affordability. After design teams revised the design idea and concepts, manufacturing teams were correspondingly required to adjust the design of the production set-up, re-schedule raw material distribution and financial arrangements. Such changes would in turn affect the marketing teams in order to re-consolidate the end-market operations in view of the company's global image, pricing and quality consistency policies. Inefficiency and ineffectiveness of activity communication and interactions at the stage of new product development would result in large magnitudes of change in the later stages of product manufacturing and distribution, so consuming significant resources and even leaving problems un-resolved. Managing interactions among interdependent activities becomes the key to effective and timely new product design and development.

In addition, collaboration is the centrepiece of interaction effectiveness. It is especially evident in the context of new product conceptualisation and embodiment. Collaboration in global enterprise functions should ensure sufficient co-existence of different perspectives, which are often domain-specific and characterised by expert judgement and professional intuition. How they interface becomes a crucial factor for ensuring proper opinion exchange and documentation. Most problems in integrating and aligning collaborative enterprises lies in inappropriate contact, conflicting opinion and poor documentation amongst these well-partitioned functional groups in different countries. Facing these collaboration issues, the buying company, pertaining to its needs, resource constraints and business environment, adopts different mechanisms and technologies to support the communication and co-ordination. Yet, it does not suffice to improve the present interactivity interaction problems.

After a series of discussions and reviews of current best practices, which purport to lead to more efficient and inter-supportive process modelling and planning, the company agreed to use the methodology developed during this investigation. Most of the information provided at this stage was aimed at improving the comprehension of the problem in more detail; the purpose was to allow in-depth process analysis and the development of an integrated global activity system modelled by using the methodological framework. During the course of the process study, the company's regional managing director, two senior managers from the information systems department and four senior merchandising/production managers from Hong Kong and Shanghai offices responded to the process profile questionnaires. To facilitate the efficient response to the questionnaires, retreat meetings were arranged to explicate the data types and levels of information detail required for the model analysis. In the meetings, the data collection procedure followed similar steps to those discussed in Section #4.3.3 in Chapter 4. The data was further supplemented and verified by two questionnaire responses from their New York Office design team. In this case the process is more human-related and involved 103 inter-country sub-activities.

The following sections are structured as follows: firstly, the observation of globally dispersed product innovation activities is recorded and the data captured for analyses of such activity systems are presented. Next, the way, in which the GA developed in the framework applies strategically to modelling activity processes and accelerating innovation process, is discussed. In an attempt to generalise what has been learnt in the cases, an additional concept framework is presented as a strategic guidance tool for managing the framework implementation for activity process modelling.

5.3.2 Process chain of global-oriented fashion product innovation processes.

In this subsection, the essential activities constituting a product innovation process in global fashion and textile businesses are elucidated. The activities are based on the research results studied in the international fashion and textiles buying company, which supports its existing world-wide fashion stores in product development and sourcing. In global fashion marketplaces, product innovation involves flows of information and opinion across a number of functional teams and inter-country enterprises that collaboratively interpret market opportunities and requirements, and transform them into a set of technology assumptions about product features and utilities. Generically, the innovation involves several distinct processes, (1) anticipating fashion trends and product opportunities; (2) developing product programmes and specifications; (3) sourcing and allocating fashion merchandise procurement; (4) organising production; and (5) arranging merchandise shipment.

5.3.2.1 Anticipation of fashion trend and product opportunities.

This involves market information searches and analytical planning to understand the concurrent market preferences and the major factors of fashion adoption. This understanding is to foresee/predict the fashion concepts that will be accepted in coming seasons. The anticipation includes observation of general market-wide developments and the environmental opportunities for fashion innovation. Furthermore, the process focuses on the characteristics of existing fashion products, their strengths and weaknesses on the basis of market popularity. Indeed the activities in this phase define not only the product specifications and the basic physical features, but also the augmented product values that will be perceived in customer's mindsets. A useful expression interpreting such product values includes sets of attributes, like fashion/aesthetic appeal, social conformity, technical performance appropriateness, perceived quality, convenience and so on. Such information is very abstract and conceptual. Because of this, the co-ordination across inter-country functional teams and enterprises is characterised by a high level of informal and context-specific communication. The process effectiveness is therefore to a great extent determined by how the activity processes are interfaced, and how well and how easy the information is transmitted and understood. During this process of product innovation, communication is very ambiguous and vulnerable. Eckert *et al.* (2000), Jassawalla & Sashittal (1998) and Milne (2000) offer very comprehensive discussions about the issues and associate them with techniques proposed to capture and trace the interaction amongst innovation teams.

5.3.2.2 Development of product features and specification.

Following the identification of market trends and preferences in the previous stage of the process chain, development teams, comprising designers, marketing teams and technical teams, attempt to define criteria to develop the portfolio and product samples in terms of fashion features that appeal to the customers' choice. It comprises choice of colours, cutting, silhouette, texture, trimming adoption and workmanship. A new seasonal design collection is sometimes compiled as a portfolio that is established to extend the existing product line, as shown in Figure 5-6. In practice, varieties of portfolio are developed for one season and screened until the final portfolio is consistent with the company's objectives.

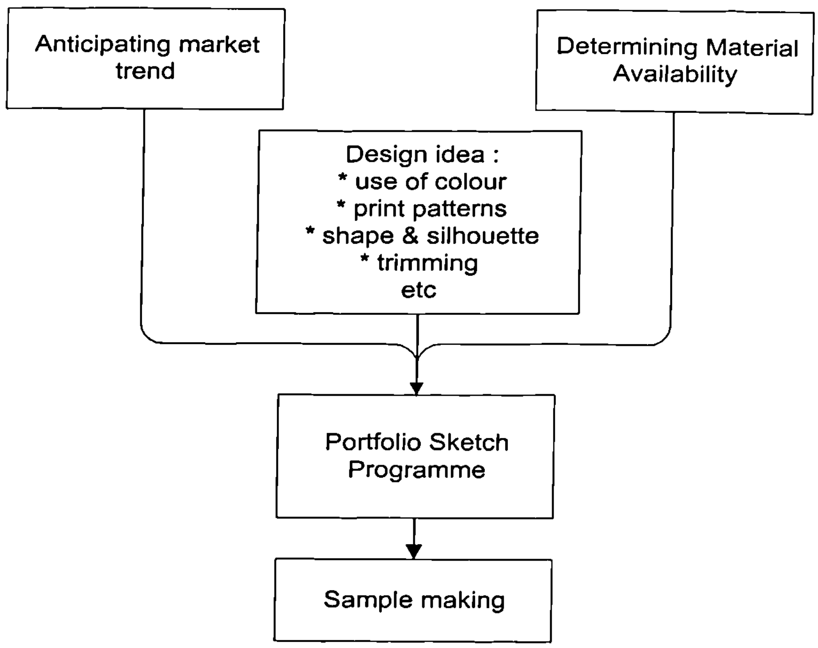


Figure 5-6 Process of fashion product portfolio planning

In brief the processes at this stage are very methodological and have to be well controlled; product innovation in global marketplaces stems from recognition of market needs and interpretation of such needs into products that possess the required attributes that convey appropriate product values to customers. Logically thinking, product innovation is guided by the overall customer consumption patterns, which are by nature evolutionary and change in pace with all other socio-technological aspects. Regan *et al.* (1998) surveyed and analysed the differences and similarities between engineering design processes and apparel design processes. The results reveal the facets to the innovation for fashion and textile products that are usually tractable and methodological, and the success of the design process is very dependent upon how detailed the innovation can be specified and communicated among all teams involved (May-Plumlee & Little, 1998; Mills, 1998)

5.3.2.3 Merchandise sourcing and procurement.

In this process the innovation activities include the search and selection of sourcing possibilities, which are in principle able to produce novel products responsively and agilely. The critical consideration during the process involves how to optimise profit, assure the least uncertainty in the supply market, schedule timely delivery and arrange the financing aspects. As observed, sourcing and procurement refer to activities of purchasing, storing, handling traffic, receiving and inspecting incoming material and salvage. The teams should anticipate and be alert to various sourcing restrictions and the methods for allocating the bases of supply according to predetermined sets of business criteria and the company objectives. Very often activities at this stage involve material management and order placement to achieve a timely production schedule. In brief, they include:

- information research of the supply market, trade or legal restriction (like quota control or tariff variations);
- checking requisition;
- analysing quotations of both material supply and the manufacturing process;
- evaluating and choosing suitable suppliers;
- scheduling delivery and order placement;
- negotiation and writing of orders;
- checking regulatory conditions of trade;
- following up on delivery;
- verifying invoices;
- corresponding with suppliers and buyers.

5.3.2.4 Organising production.

This stage of the process-chain emphasises how to arrange production, define the quality level, schedule material requirements and delivery, and allocate control personnel. The process involves activities for the expedition of material ordering and receiving, inspection, resolving technical problems and arrangement for finished product packaging and dispatch.

5.3.2.5 Design and selection of merchandise distribution channels

These last stage activities are to examine the distribution channel member performance and holistically decide on the logistic systems. It involves planning and orchestrating transportation methods and routes, packaging and handling methods and finally optimises the best arrangement of delivery for all the other parties concerned. Using our framework, we establish an IDEF0 flowchart to represent the above observed innovation process and model the product innovation activity structure and relationships in detail, as shown in Figure 5-7.

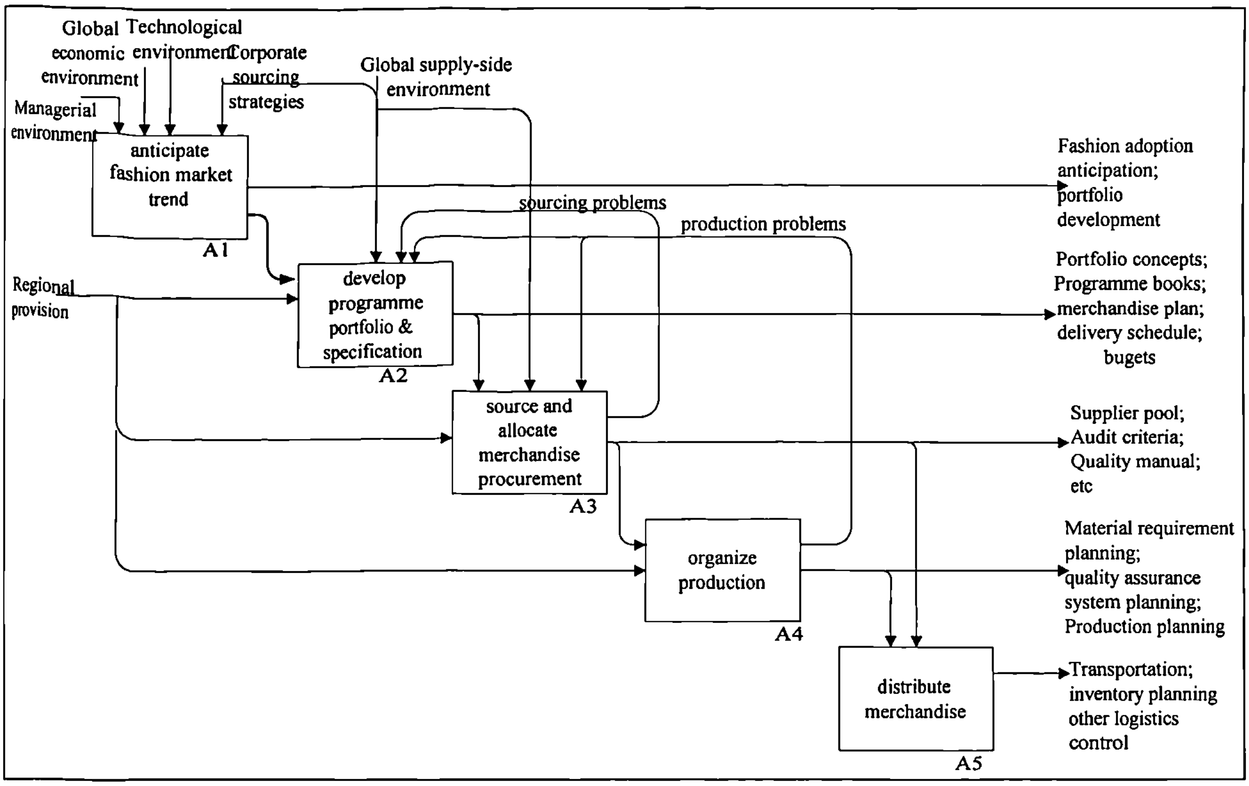


Figure 5-7 Activities of fashion product innovation for global marketplaces

The flowchart corresponds with the structure of activity interdependency that is established in the course of new product innovation and development. This workflow process can be decomposed structurally into more detailed levels of activity hierarchy, based on a top-down analytical breakdown approach. Such decomposition provides the gradual exposition of detail by expansion of the contents of the activity boxes from one level to deeper and deeper levels. The box numbers act as convenient indices to search for levels of exposition of activity tasks. An index of the activities researched in this case are listed in Table 5-5. As stated, there are 103 decomposed activities operated by a number of technical and functional teams in different locations.

Table 5-5 Fashion product innovation activities in levels of detail

Activity Name List

1	Determine Trend Preference	A111Examine trend setter reports - fashion adoption	
2		A112 Examine novelty diffusion patterns	A1121 Determine desirable seasonal cycle time
3			A1122 Determine seasonal sales fluctuation
4		A113 Measure market expectations	A1131 Assess life styles of end-market users
5			A1132 Assess ethical issues in fashion markets
6			A1133 Assess technological advancement in fashion products
7		A114 Remark contemporary socio-cultural issues and events	
8	Determine Market Variables	A121 Examine end-use consumers	A1211 Segment consumer groups
9			A1212 Measure segments' market sizes
10			A1213 Measure consumption power and patterns
11		A122 Examine distribution channels/outlet performance	A1221 Examine distributors' performance
12			A1222 Examine store location profiles and performance
13			A1223 Measure competition profiles
14		A123 Determine product profiles	A1231 Assess brand profiles
15			A1232 Assess line profiles (depth and breath)
16			A1233 Measure complementary service/operation performance
17	Conceptualise Product Design	A211 Budgeting	A2111 Access and fix capital provisions

18			A2112 Determine costing policies
19			A2113 Determine markup-markdown policies
20		A212 Design programme scale and collection frameworks	A2121 Plan on-floor product distribution cycle and schedules
21			A2122 Determine seasonal volume and buffers
22		A213 Position product values/benefits	A2131 Develop/adapt logos and labels
23			A2132 Design/develop visual merchandising
24		A214 Design product features	A2141 Design material adoption
25			A2142 Design styling and story frames
26			A2143 Design construction methods and workmanship level
27			A2144 Design colourway/line combos
28			A2145 Select care instructions and tag-on materials
29		A215 Establish quality standard and policies	
30		A216 Develop portfolio sketch books	
31	Adapt Regulatory Aspects	A231 Examine environmental and safety requirements	A2311 Evaluate ad select dying processes
32			A2312 Evaluate and select add-ins finishing properties
33		A232 Examine overall collection image and quality consistence	
34		A233 Examine the detailed trade restrictions and practices	A2331 Evaluate and select control quota categories
35			A2332 Evaluate contemporary tariff and duty restrictions
36			A2333 Examine contemporary blacklisted materials & finishing
37	Consolidate Market Requirements	A241 Product screening and modifications	A2411 Fitting and sizing
38			A2412 Confirm colourways, prints, frames, silhouette
39			A2413 Streamline collection components
40		A242 Consolidate market feedback and order quantity	A2421 Arrange collection presentation, trade shows
41			A2422 Prepare catalogues
42			A2423 Streamline collection breakdown
43			A2424 Re-schedule material consumption
44		A243 Confirm seasonal portfolio and buying capacity	A2431 Open PDM files and item digital IDs
45			A2432 Consent delivery schedule
46			A2433 Conclude material specification and variation allowance
47		A244 Issue buying plans and buying buffers	
48		A245 Determine procurement tactic and	

		policies	
49		A246 Determine contingent orders for market uncertainties	
50	Determine Sourcing Metrics	A311 Determine potential supply countries	A3111 Evaluate materials/quantity availability in countries
51			A3112 Project uncertainty
52			A3113 Design materials/production workflow process amongst countries
53			A3114 Evaluate and optimise cost and lead-time
54		A312 Allocate proportion of purchase orders to potential suppliers	
55		A313 Assess individual supplier performance	
56		A314 Decide critical order placement criteria	
57	Determine Sourcing Channels and Co-ordination	A321 Compare and develop sourcing channels	A3211 Accredit suppliers and open supply account
58			A3212 Determine contractual relationships
59			A3213 Develop affiliated sourcing agents and offices
60			A3214 Evaluate logistic performance
61		A322 Determine co-ordination and control mechanisms	A3221 Install communication infrastructure
62			A3222 Design communication procedures/documentation
63		A323 Assign buying teams duties and supply site visits	
64	Negotiate Order terms	A331 Negotiate delivery terms - conditions	
65		A332 Adjust allocation of purchase orders	
66		A333 Adjust order details	
67	Proceed Order placement	A341 Enter into procurement contract	
68		A342 Work out credit loan facilities	
69		A343 Select financial supports and estimate periodic capital return	
70		A344 Plan credit sources (undertakings)	
71		A345 Confirm credit issuance	
72	Embody Product Design	A401 Make prototype samples	A4011 Make fabric strikeoff
73			A4012 Make accessory samples
74			A4013 Make colour lab-dips
75			A4014 Evaluate material properties and potential problems
76			A4015 Evaluate finishing and/or washing processes
77			A4016 Make garment samples

78			A4017 Evaluate fibre components
79		A402 Develop collection and salesman samples	
80		A403 Establish testing standards and technical specifications	
81	Organise Production Processes	A411 Plan manufacturing processes	A4111 Engineer patterns/markers/grading
82			A4112 Engineer cutting process
83			A4113 Engineer line balancing and component flows
84			A4114 Design pack and finishing works
85			A4115 Engineer machine setting
86			A4116 Engineer plant layout
87		A412 Make approval samples	
88		A413 Estimate material utilisation	
89		A414 Material requisition	
90		A415 Machine/equipment requisition	
91		A416 Assign jobshop loading	
92	Monitor Production Quality/Progress	A421 Measure in-line performance	
93		A422 Measure final performance	
94		A423 Develop inspection systems and procedure	
95		A424 Audit and amend quality-related variation	
96	Co-ordinate Auxiliary Services	A431 Decide levels of automation and WIP processing	
97		A432 Design documentation and expedition procedure	
98		A433 Plan/restructure functional staff	
99	Schedule Traffics	A511 Schedule carrier rota	A5111 Estimate ship space
100			A5112 Reserve shipping capacity
101			A5113 Assign sale digital barcode
102	Co-ordinate Logistic Works	A520 Document inventory information	
103		A530 Construct accounting and financial systems	

The case studied represents a globally oriented virtual enterprise concept; whereby fashion and textile products are characterised by world-wide development and distribution. The company orchestrates and monitors the operations of the global supply pipelines in a manner which approximates to a single integrated manufacturer. By this means it co-ordinates a large number of interdependent enterprise entities across different countries. Therefore, virtual enterprising is closely related to various kinds of enterprise integration or alignment through the application of virtual technologies. Fundamentally, it inevitably involves a great number of functional and technical teams in countries that continually exchange their own perspectives and information during the cycle time of the fashion business. The company studied in this case managed to use well-defined contact schemes and structured document flow to cope with the logistic problems. It is evident that such dedicated communication and document flow systems do ensure the adequacy of their communication and interaction. However, it is still problematic to ensure a high degree of collaboration supporting the shared vision and understanding across globally dispersed enterprises. This explains why effective and integrated activity processes cannot always be maintained without proper treatment of interactivity dependency especially during the early stages of activity planning.

In reality, the product innovation process is highly iterative. Often, iterations occur when problems in the different activities are unexpectedly diagnosed and the information disseminated to other activities, or when new market opportunities or threats are recognised during the course of the innovation process. A large number of activities and teams makes team interaction complicated and non-schedulable during the innovation process. The data surveyed in this research identified 59 pairs of activities which were intimately interdependent and form one of the key sources of process repetition. Any change during the process would result in unpredictable impacts propagated among the interacting activities. Fashion market requirements are very capricious and the current practice is to manage a very short sale cycle period of around four to six weeks on the retail floor. That is, the decisions eventually made to any problem found are whether and how the delivery of a new product is delayed or whether it is held over to the next season. The intent of this case study was to apply the framework in an attempt to model and improve the existing product innovation process from a global integrative perspective.

At the beginning of this case study, it was stated that activity modelling is somewhat tautological. The undesirable iteration problem during innovation processes was already known by most of the company staff. However, such familiarity may actually be the heart of the problem, i.e. that staff take the process iteration for granted and assume that it is unavoidable. One of our efforts in use of the framework was to make the modelling sufficiently separate from the management's conventional views, and so improve and accelerate the interdependent activity processes. The purpose was to allow the fashion company to postpone product decisions to the last possible moment, keeping pace with the volatile market requirements.

5.3.3 Strategic use of the framework to accelerate innovation projects

In the previous case study, the methodologies built in the framework were used to restructure the interdependent activities in an innovative plasma treatment process and the approach was outlined for evaluating innovation performance in scheduling and optimising expected cycle time. Indeed, the majority of extant literature advocates fast and responsive activity processes to deliver novel products. In our framework, activity process restructuring leading to shorter process cycles stemmed from the partitioning and decoupling of interactivity dependency, allowing activities to proceed concurrently. However, should all the innovation be indiscriminately accelerated by concurring activity processes? Is there a trade-off between shorter process time and cost added to restructuring the activities? Again, what is the proper activity structure to sustain successful innovation in different organisation and market contexts? Successful innovation activities are determined by balanced strategic decisions based upon the interlaced factors of costs, time and uncertainty. There is no single rule that fits all. Therefore an additional concept framework was developed to feature strategies of use in the modelling framework. The concept framework is to generalise implementation of the methodology proposed to managing global activities.

5.3.3.1 An additional concept framework

The concept framework is derived and generalised from the observations in this second innovation case. Although these observations concern the innovation of fashion products, the principles and concepts are generic and available for application to other innovation activities. Collectively the modelling framework presented uses the restructuring of activity interrelationships, and the respective opportunity gains in terms of time, to identify the possibility of better activity co-ordination and management.

Restructuring activity interrelationships means changing the nature of the activity interaction and the ways they depend on each other. In this framework the restructuring changes are either by restricting backward process dependencies or by totally decoupling interdependent relationships. Here we boldly hypothesise and assert that the more interdependent activities are decoupled and concurred, the higher are the opportunity costs required to restructure the activity processes. These costs will be incurred in redefining, combining and concurring the activity tasks, which consequently lead to re-allocation of facilities and staff with different expertise to tackle such changes. Further, the more activities are detached and allowed to overlap, the more versatile the innovation teams are expected to be so that people can collaboratively share, discuss and digest the information provided by different disciplines during the innovation.

By reducing the process cycle time, it means that management is able to make decisions and action responses at the last possible moment, keeping innovation in pace with the changing and unpredictable market information. In other words, it refers to an alternative strategy to manage the issue of uncertainty for differentiated global marketplaces. On the premises of these two dimensions, it is proposed to categorise two extreme activity structures (perhaps inter-organisation structures) to cope with different innovation requirements, as shown in Figure 5-8.

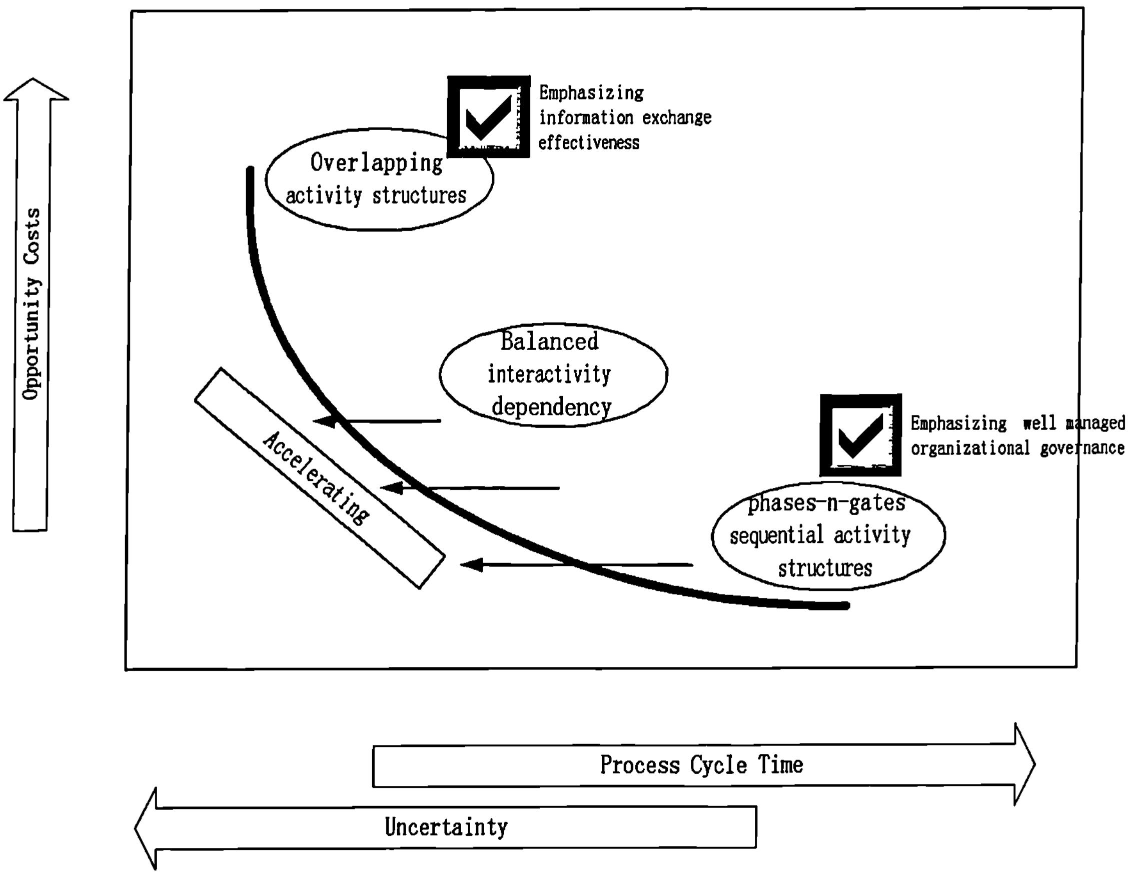


Figure 5-8 Strategies for managing innovation activities

5.3.3.2 Sequential activity structures

In this extreme strategy, activities are well partitioned and structurally sequenced. It is more appropriate for those markets in which the innovation requirement is comparatively stable. Process cycle time takes longer but the results of each activity task are relatively certain. As a result management keeps tight control and monitors process progress among interdependent activities and teams using defined management policies and practices; otherwise, the process progress tends to be extended unconsciously as each predecessor activity restricts the start of dependent successor activities. Commonly, frequent and formal progress reviews and revision of market innovation requirements are needed, so ensuring "everything is right and adequate" with minimum probability of activity task reworking and rescheduling.

Therefore it demands relatively less response effort and cost to cope with changing market requirements. This is one of the major merits of such a strategy for managing innovation activities. In the course of innovation, activities are well partitioned and sequential, requiring teams specialised in different areas of expertise. Resources can be optimally distributed toward appropriate functional teams that are responsible for specific areas of activities. Figure 5-9 shows the manipulated DSM, in which 20 out of 59 interdependent activity pairs are optimally redesigned to restrict backward dependent workflow. Hence, the activities are re-sequenced and scheduled with minimum backward process dependency. To facilitate such a type of dependency, appropriate organisational integration should be adopted, including skill standardisation, work process standardisation, formal interactivity team meetings, team collocation and so forth.

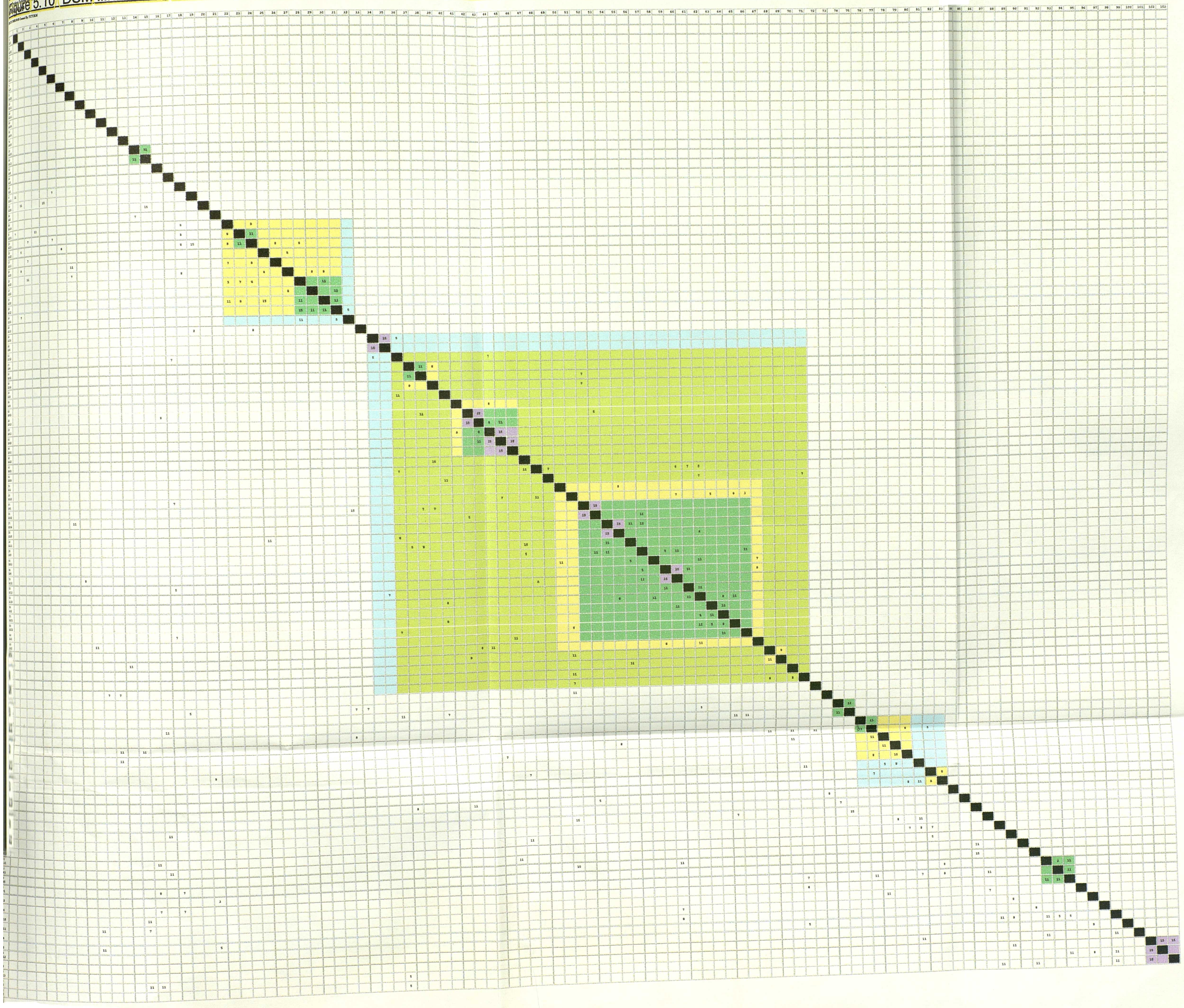
5.3.3.3 Overlapping activity structures

With an accelerating process cycle time and high opportunity costs for activity restructuring, an overlapping activity strategy, which emphasises process concurrence, will be clearly appropriate for unstable innovation requirements in the end marketplaces. Fashion inherently means changes. International fashion companies prefer to respond to markets on a "real time" basis, i.e. actions and decisions made in a very short time-scale can accurately and sufficiently serve market demand responsively and timeously. Innovation activities are therefore accelerated by maximising the degree of overlapping. Innovation teams intensively interact and collaboratively support each other. As such the uncertainty issues of innovation can be minimised.

Figure 5-10 illustrates a restructured DSM, in which all of the interdependent relations between a number of activity pairs are optimally broken by the GA and such activities are allowed to concur; i.e. both forward and backward dependencies are decoupled. This provides maximum levels of activity concurrence with the shortest process cycle time committed to innovation projects. However since the activities are managed with a maximisation of activity overlapping, the opportunity costs and effort for re-sequencing and re-designing activity tasks will be comparatively high.

To facilitate the concurrence, activity interaction should ensure operation with highly efficient information exchange and dissemination. The dependencies in such environments tend to be very strong and information oriented. Appropriate information integration, like data standardisation, knowledge-based virtual document systems, and integrated messaging, can support and control process consistency and overcome the activity overlapping barriers which stem from different geographical, organisational and even cultural sources. After reviewing the preliminary results of this research, the fashion buying company decided to develop an even more advanced document management and interface system that allows the creation, review and revision of product innovation information by designated teams on a networked basis. As such, a designated number of remote users can simultaneously view common virtual images of novel products on their monitors, manipulate images at any time, and pass information back and forth between participating users.

Figure 5.10 DSM illustrating partitioned strcture after interdependency relations of a number of activity pairs are decoupled



5.3.3.4 Balanced activity dependency structure

In most cases, management of process time and opportunity costs cannot be considered separately for successful innovation projects. In real-life practices, the greatest challenge for management is to strike a balance between the time, costs and risk committed to innovation. For different market innovation requirements, time, costs and risk do not imply the same degree of decisiveness.

Table 5-6 Extracted GA analysis results in process lead time reduction in fashion product innovation process

(Simulation results: expected lead time, weeks)	Degree of overlapping (no. of selective interdependent activity pairs to be decoupled)						
		0	10	15	20	25	30
Decoupling backward process dependency	Best	39	28.5	28	27.5	27	27
	Worst	60	42	50	49	50	50
Decoupling interdependency	Best	33	28	28	27	27	26
	Worst	55	47	51	48	47	47

Table 5-6 extracts the figures of expected process cycle time and the corresponding degree of activity overlapping (decoupling), which are analysed by the GA framework. The fashion company has to adopt a balanced approach that strategically combines the above dependency structures to design and manage types of market innovation requirements. A balanced structure approach means that a strategic trade-off decision is required between these dimensions in the concept framework. The methodological framework presented provides a novel means to measure and analyse data for such trade-off decisions and their implementation. As referred to in Table 5-6, the higher the degree of activity overlapping by the GA evaluation, the greater the lead time is reduced. When we increase the number of interdependent activities that are to be decoupled, the simulated process lead time will gradually decrease from the original estimation 39 weeks to eventually 26 or 27 weeks. In addition, the GA can simulate another important result of restructuring the activities from the viewpoint of expected lead time variance. As stated in Table 5-6, though decoupling the 10 specified interdependent activity pairs cannot give rise to the shortest time span, it can allow the least variance of time to proceed the activity process cycle. The examples of the GA analysis results for the process structural changes are shown in Appendix A at the end of thesis and will not be discussed here.

Activity structuring can be categorised strategically into two extreme approaches, phases-and-gates sequential and overlapping approaches, based on the opportunity costs incurred to change the activity systems and the lead time needed to complete the process. For each approach, appropriate types of activity structures and interrelationships in terms of process flow interdependency can be identified. To support implementation of the types of innovation activities, we make use of various organisational and information integration mechanisms to control and monitor the activity interaction and the use of resources. A point that we have to emphasise is the balanced strategy approaches for different market innovation requirements and competitive advantage strategies.

5.4 Conclusions

The two case studies affirm the two main goals of this research. First, they show how the methodological framework proposed can identify and represent structures of critical business activities using the dependency-based modelling methodology in the context of the innovation process for global marketplaces, characterised by intensive information exchange in non-hierarchy network patterns and a high level of process uncertainty (non-scheduled stochastic iteration). Second, they illustrate the ways that the innovation performance is altered by the changes of interdependency among a large number of globally dispersed development teams from the perspectives of information and organisation management. In the case of plasma treatment innovation the framework was applied to model the interdependency of the 22 activities workflow. In this case, we presented and discussed the interpretative procedures to manipulate the interdependency structure, remodelling the activity processes in a desirable manner. In the second case, an international fashion buying company is studied and 103 activity tasks are identified. Using the case, we generalise the observations and findings in this research into a concept framework that can provide strategic insights for designing and managing globally dispersed business activities. In addition, the concept framework enables the choice of appropriate activity structuring approaches and integration mechanisms to monitor the interactivity interaction.

CHAPTER SIX: ASSESSMENT AND CONCLUSIONS

This chapter discusses the validity of the framework and presents a corresponding framework life cycle used as an institutionalised learning mechanism. In the context of the aims of this investigation, the implications and contributions that the framework proposed brings to managing global fashion innovation are summarised. The results and the validity of the framework applied in the case studies are discussed through a series of hypothesis reviews. The facets to the problem of framework implementation are also discussed. Finally the framework is extended toward a mechanism that entails the investigation of activity process systems as an organisational life-long learning cycle and proposals are outlined about the future direction of work that could follow on from this study of modelling innovation processes and activity process interdependency.

6.1 Implications and contributions of the methodology framework for managing innovation activity processes

As stated earlier, innovation management in this research is perceived as managing process-based interactivity dependencies to achieve desired goals of competitive advantage in the management of global supply pipelines, either by means of product or process development. Within this context the framework developed in this thesis makes the following contributions to managing innovation activity processes:

(1) The thesis articulates the need for a new methodological approach that deals with interdependency issues for managing process-based innovation work.

(2) The thesis addresses some basic aspects of activity process management, process engineering, and methodological design theory literature in the innovation management context.

• The thesis explains the significance of today's fashion business globalisation and the alignment of process activities that form an integrated set of companies which operate as a single, virtual, enterprise in a global supply pipeline.

• The thesis examines the different views expressed in the literature for managing and designing global activities for innovation processes.

• In addition, it generalises the theoretic methodology approaches to cope with process design and development.

(3) The thesis develops a methodological framework, forming a disciplined method to model and manage activity processes.

• The thesis expands the existing modelling concepts and procedure to measure and properly represent the activity interrelationships, which arise from different types of interactivity dependency.

• It advocates and construes interdependencies as stemming from two generic dimensional attributes, processing information 'vitality' and the interactivity organisation 'governance'.

• It measures the strength of these two dimensions on the basis of multi-attribute utility theories that value different objective preferences and convert them into a common preferential scale.

• It develops an elicitation procedure to capture modelling input data that are characterised by expert judgmental knowledge and subjective opinion.

(4) In the cases studied, the framework is used as an analytical tool to examine activity system structure interpretively and to explore how the activities may be re-structured more effectively. Moreover, it introduces a framework for evaluating process cycle time through a genetic algorithm that suggests the optimal changes of activity interdependency relationships. In conventional exact methods, the evaluation is NP hard and it is difficult to find solutions in determined time. Making use of the GA provides a cost-effective programming procedure to rationalise large scale activity structuring.

(5) The work establishes an additional concept framework that generalises principles and strategies for using the methodology to manage innovation activities and the respective concepts of choice of integration mechanisms. Two strategies of activity structuring are suggested:

- an overlapping activity structure that enables a maximum level of process concurrence and emphasises efficient information exchange through seamless information systems, knowledge standardisation and versatile innovation teams.
- a phases-and-gates sequential structure that maintains effective forward process progress through periodical process reviews and revision, and restriction of possible process iteration or control of process iteration within appropriate specified limits.

In summary, the frameworks presented in this thesis intend to benefit those concerned with management and design of globally dispersed activity processes, especially in innovation areas that feature high degrees of uncertainty in respect of the process requirements and may cause intractable process iteration among interdependent tasks. It also helps to give advice to management about the beneficial impact of prioritising activities that have to be re-structured and re-sequenced. Yet the framework still follows the universal philosophy that regards models as useful only when a set of framework assumptions are fulfilled and valid. The next section discusses the framework validity and assessment of the case study results.

6.2 The validity of the framework

Dependency-based process modelling undoubtedly has a significant impact on today's activity and project management. Its philosophy emphasises horizontal integration, cutting across all well-partitioned functional units and teams, and makes the definition of an activity task distinguishable from conventional management in which activities are function-oriented and activity team units tend to be self-contained. In dependency structural modelling, process workflow design is built on a holistic basis, attempting to examine the entire activity structure and the potential consequence propagated by any change among interdependent activities. An interdependency stands for a pattern of precedence of interrelated activities and the strength of such interdependency is related to the extent of vitality of one activity that depends on preceding activity(ies). However, is the framework really capable of representing the process workflow behaviours in real-life situations? Is it too simplified? Or is the dependency in the framework not construed sufficiently and completely? Indeed the usefulness and validity of the framework are very sensitive to the set of modelling hypothetical assumptions we make to infer the actual activity processes. The assumptions are stated explicitly and discussed below.

6.2.1 Hypothesis of the dependency-based framework assumptions

The main hypothesis is 'that innovation management can be better managed through explicit specification and co-ordination of process-based decomposed activities that, during the progress of the process, influence one another and form various types of interdependent process relationships'. The models established by the framework can represent the activity interrelationship and depict activity workflow process behaviour using a nomenclature of interactivity dependencies.

- The sub-hypothesis is 'that innovation processes can be improved through decoupling interdependent activities'; in other words, from graph theory, the process path tends to be shorter as the circuits in a graph are heuristically unwrapped and broken.

The **second hypothesis** is 'that the modelled dependency construct is matched with actual measured dependency behaviour'.

- Sub-hypothesis 1 is 'that the two dependency attributes are sufficient to represent the essence of all interactivity dependency and are nomologically stable'.
- Sub-hypothesis 2 is 'that the two dependency attribute measures can be converted into the single multiplicative utility form which is appropriate and consistent, when used for construing the total interactivity dependency concept'.
- Sub-hypothesis 3 is 'that the interval scale of each attribute measure is appropriate and adequate to discriminate over the range of the dependency'.

The **third hypothesis** is 'that the genetic algorithm developed in the framework provides a meaningful procedure that is applicable to evaluate similar kinds of behavioural problems of activity systems; it provides an inexact, but adequate, method for restructuring interdependent activities.

6.2.1.1 Main hypothesis review:

Main hypothesis: Innovation management can be better managed through explicit specification and co-ordination of process-based decomposed activities that, during the process progress, influence one another and form types of interdependent process relationships. The models established by the framework can represent the activity interrelationship and depict activity workflow process behaviour using a nomenclature of interactivity dependencies.

Whether this hypothesis is accepted as valid depends much on whether the framework appears to truly model what it purports to model. Or simply viewed, the framework should firstly be tested to determine whether it is sensible enough and sufficient to represent the real situation of activity process systems and predict the corresponding system behaviour. The validity is not to be judged by the extent and level of detail the framework can provide, but by its ability to make valid predictions that, otherwise, would not have been considered, or by how much it leads to a better understanding of the process system. The framework developed in this thesis is to model the structure of innovation process activities. Activities herein are defined on the basis of input-output information processing concepts. During an innovation process, the innovation goals or objectives are accomplished by a group of expert teams and resources that are individually assigned to undertake specific tasks and resolve various sets of innovation problems. These problems are commonly very technical and often ill-structured. The teams therefore required close and frequent interaction to deal with the problems collaboratively. Their interactions form some characteristic interactivity relationship which defines how they interrelate in the innovation process. From structural points of view, such relationships result in various kinds of activity precedence or sequential dominance; i.e. some activities are predecessors and some are successors. As such these relations between activities give rise to the types and extents of dependency observed. As such it is logically true to assume that such phenomena of dependency can be observed and interpreted as an activity structure.

In the cases studied, the experts and the practitioners unanimously agreed that the whole innovation process should not be investigated as separate parts or on very detailed level of the activities. Rather, the most valuable analysis in activity planning and modelling is at high levels of decomposition which consider the whole process holistically; this is exactly what the framework was designed to achieve. Furthermore, the innovation experts in the fashion company accepted the view of activity structure in terms of dependency and that it truly and sufficiently reflected the structural nature of the innovation processes. By this means, the innovation process system is defined and decomposed into activities that receive and proceed distinct input information from the preceding upstream activities, and disseminate such information as output toward the succeeding downstream activities. That is, some activities are sequentially dependent, some independent and some interdependent. The nomenclature of interactivity dependency underlies the basic theme of activity process modelling.

6.2.1.2 A sub-hypothetical point

Sub-hypothesis: innovation processes can be improved through decoupling interdependent activities; in other words, from graph theory, the process path tends to be shorter as the circuits in a graph are heuristically unwrapped and broken.

In the framework proposed, the dependency relations between activities are displayed within a matrix. Each row and its corresponding column represent one activity. If activity A provides information as output toward activity B, then a mark is shown in the intersection of column A and row B. This is a dependency mark. By this means the matrix can be populated with such types of dependency marks, showing a structural flow of working information. Represented in graphical form, this information workflow diagram gives rise to a critical path to schedule the time taken to proceed the whole process.

If, for a given pair of activities A and B, dependency marks appear in both the intersection of column A-row B and column B-row A, then they are interdependent and form a circuit indicating that activity A receives input information from activity B and also provides output information to activity B. Process iteration is anticipated for a certain number of times; therefore for conventional critical path analysis, it is possible to unwrap the circuit by laying it out end to end for the number of times it is to be iterated. Once such a circuit is broken, the iteration tends to be controlled. The manipulation of a dependency structure matrix is to strategically search the marks that, once torn, generate in the greatest desirable impact caused by from the structural change. As illustrated in the two case studies, the significance of the approach for process re-planning and re-scheduling is revealed as repeated application of the GA generates unexpected, useful, solutions for consideration.

Often technical teams prefer to refine information in an innovation process by doing more iterations, while management teams tend to avoid the effort and costs involved in the extended iteration processes. For fashion businesses, time is the major critical factor to sustain competitive advantage; the fashion product life cycle curve is very narrowly skewed and demands an accurate estimation of time-to-market. Modelling activity process should address the iteration issue resulting from interactivity dependency and allow activity restructuring to cope with the external market requirements, which could otherwise lead to erroneous decisions and untenable scheduling plans. The prediction of the framework that accounts for iteration as arising from interdependency makes intuitive sense and meets the reasonability criterion of modelling.

6.2.2 Construct (internal) validity: dependency concept construct

Second hypothesis: the modelled dependency construct is matched with actual measured dependency behaviour.

This hypothesis concerns the construct (internal) validity of the dependency concepts. It refers to the extent of correspondence between the dependency construct that is perceived at an intangible, conceptual level and the purported measure of dependency that it is designed to generate for operational use. That is, it tests how convincing the measure of dependency is to assess, sufficiently and representatively, the magnitude and characteristics of the empirical interactivity dependency. The dependency construct proposed in the framework comprises two attributes, the vitality of information that activities are dependent on and the organisation governance that forms dependent rules or restrictions among activities. This hypothesis argument is considered under the following three sub-hypotheses.

6.2.2.1 the first sub-hypothesis

Sub-hypothesis: the two dependency attributes are sufficient to represent the essence of all interactivity dependency and are nomologically stable.

As stated earlier, researchers (Eppinger *et al.,* 1990; Wang, 1995; Yassine, 1999a) use somewhat similar constructs to represent and measure interdependency among activity tasks. All of them concern the characteristics of information exchanged between activities and are proved to be intuitively sensible particularly in activity processes focusing on engineering design and development. However, since the dimensions of dependency constructs are closely related to the aspects of exchange of product development requirements and technical relevance, the nomological validity showing the coexistence of different but closely related dimensions is very arguable. Respondents may not perceive and discriminate the closely construed dimensions consistently. Instead, the framework proposed in this research used an alternative construct comprising an attribute of vitality of dependent information and another attribute, arising from the organisational control policies, which has a long history in the organisation and management literature (Crowston, 1996; Victor & Blackburn, 1987). The new construct proposed in this framework is mainly based on the results evaluated in the extant literature. When applied to the cases studied, the majority of respondents interpreted and used the dimensional attributes consistently without significant ambiguity. Through interaction with the respondents in the cases studied, opinions on the use of the dependency constructs was reviewed qualitatively. The variability of the framework in measuring dependency concepts was empirically reduced and data gathered maintained a high degree of repeatability and accuracy from a qualitative validation viewpoint. In both cases, the innovation teams appeared comfortable with the way that dependency was construed and appreciated its advantages compared to alternative approaches which mainly addressed the vitality of information proceeded between activities.

6.2.2.2 the second sub-hypothesis

Sub-hypothesis: the two dependency attribute measures can be converted into the single utility multiplicative form which is appropriate and consistent when used for construing the total interactivity dependency concept.

The framework proposes a utility-based measure converted from the two mutually distinct dimensional attributes in multiplicative form. Utility theories underlie the evaluation of preference decisions with multiple objectives where the value of each cannot be directly compared e.g. cost, time, risk and preference over objects. Theoretic aspects are rigorously treated and recorded in several seminal papers and texts (Keeney & Raiffa, 1993; Thurston, 1991; Kirkwood, 1997) and are not illustrated here. Surveyed from current literature, only Yassine *et al.* (1999a) attempted to use a similar approach to measure dependency, but in a more tedious way; Yassine defined dependency using direct multiplication of two utility attributes on a 1-to-4 interval scale for all pairs of activities in systems, i.e. $\text{Utility}_{\text{overall}} = U_{\text{attribute1}} \times U_{\text{attribute2}}$. Hence, it assumed that the dependency comes into being only when the two attributes co-existed and the interactivity dependency arose prevalently from the process of information exchange. In the framework used herein, individual, single, attributes can exist and contribute to the formation of interactivity dependency, i.e. $\text{Utility}_{\text{overall}} = (U_{\text{attribute1}} +1)\ (U_{\text{attribute2}} +1) -1$. This is necessary and appropriate enough for the purpose of analysis in cases where the dependency of large and dispersed global activities actually arises from a great deal of organisation control policies coupled with substantial information vitality. Through empirical tests, it was recognised that the multiplicative form is valid and could be conveniently applied to the real situation.

6.2.2.3 the third sub-hypothesis

Sub-hypothesis: the interval scale of each attribute measure is appropriate and adequate to discriminate over the range of the dependencies.

This relates to the validity of the discrimination between rating scale intervals. An extended rating scale provides better resolution to distinguish levels of dependency purported to be assessed. However respondents may be confounded in their capability to discriminate between finer levels of difference. Two extended scales of 6- and 8-intervals were evaluated; it was found that respondents tended to rate within a narrow (central) interval range of the extended measuring scales. The choice of scale interval is actually a balanced issue between these two conflicting aspects. In the framework we use four levels for each attribute. In the multiplicative form, it extends into eight levels of strength of dependency. The extent of the dependency assessed appears adequate and reasonable.

In summary, the hypothesis reviewed above illustrates that the predictive nature of the framework construing interactivity dependency is recognised within certain applicability to model activity process, and are accepted qualitatively and are theoretically valid.

6.2.3 Evaluation (internal) validity: the GA models

Third hypothesis: the genetic algorithm developed in the framework provides a meaningful procedure that is applicable to evaluate the same kinds of behavioural problems of activity systems; it provides an inexact, but adequate, method for restructuring interdependent activities.

Fundamentally, the GA procedure searches heuristically for the expected process cycle time with the optimal interactivity dependency structure as the key objective function. We may argue why a GA is adopted to evaluate the combinatorial problems of optimal activity dependency structures. Indeed today's large-scale computer cluster technology (supercomputer) has power which can support such problem evaluations using a range of exact methods, like dynamic programming, and branch-and-bound techniques. However, the computation cost is very high and raises the question of affordability. The GA developed in this research provides nearly optimal, although inexact solutions, for making strategic decisions contingently. In the cases of the international buying company, the innovation concerns 103 interdependent activities and demands a great deal of endeavour to unveil the mystery of the system's structure. The GA procedure can dissect the problem confidently and affordably.

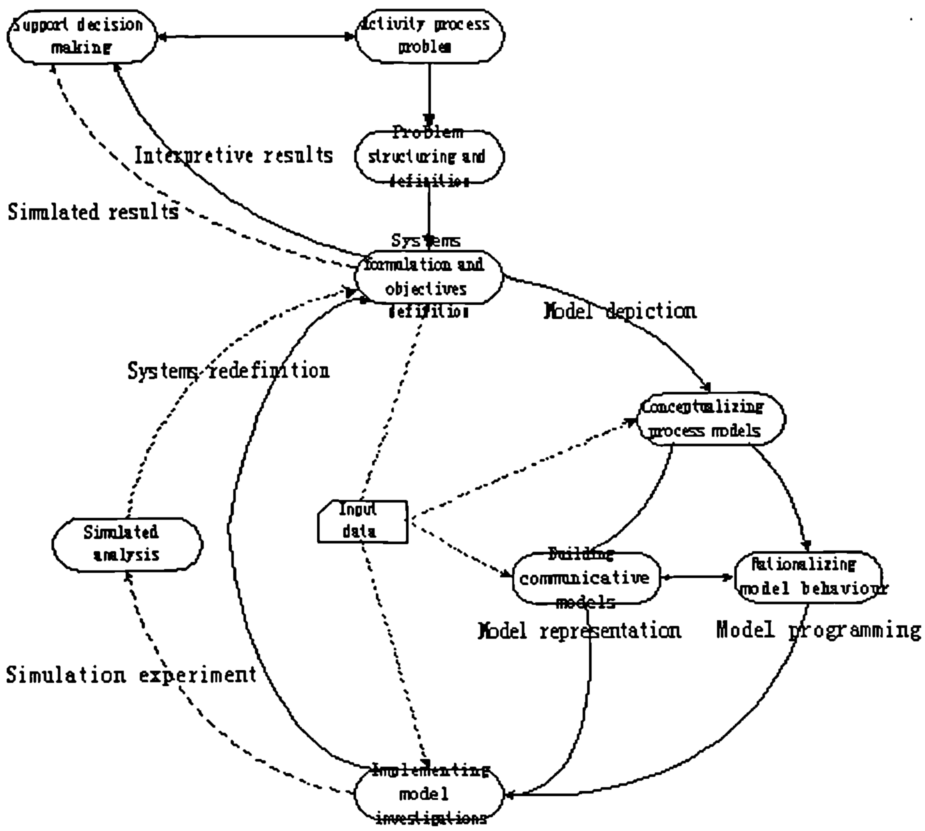
Again, the GA models and evaluates the process behaviour efficiently by simulating process iteration due to interactivity dependency. This assumption is accepted as true and valid because the results derived from the GA generates quantitative results substantially matching the common observed behaviour of the process. Through the two sets of case observations, such substantiality is judged empirically and recognised positively by the experts involved in the innovation activities.

6.2.4 Assessment from industry and academia

The research framework is shaped and supported by different perspectives on management of global supply activities from the opportunities provided within the investigation to discuss and publish the research ideas and progress. Fortunately, the hypothesis assumptions of this thesis are widely accepted and supported. Despite the inexactness in respect to the GA evaluation, the methodology framework provides benefits to industry and academics aiming at improving complex cross-enterprise activity processes, especially for exploration of competitive novelties. Perhaps, it is attributable to the excellent power of predicting the impact propagated from structural changes on the process re-scheduling and re-planning from the dependency perspective. Further the vitality of the framework in the area of process integration and concurrency is found particularly critical for today's management concept of globalisation, which focuses reconfiguration on inter-country activities and alignment of competitive competences. In the last section of this thesis, conclusions are drawn on the opportunities provided by the framework for management in innovation process and future work that could follow from this framework concept.

6.3. The life cycle of use of the framework as a continuing learning mechanism

Figure 6-1 presents a framework life cycle as a formalised learning process, through which enterprises could improve process performance repeatedly within enterprise-wide practice. The life cycle built is generic, purporting to move the framework developed in this thesis towards an established status.



Life cycle of use of the framework as a continuing learning mechanism

Figure 6-1 Life cycle of use of the methodology framework as an established learning mechanism

The life cycle should not be interpreted as strictly sequential; indeed it is recurrent in nature; a need for process improvement may necessitate returning to earlier stages of the life cycle and starting all over again. When we recognise problems of some particular activity process, management initiates a study and communicates with different teams and experts to specify what are the real sources of the problems. Problem structuring and definition is the process by which the observed problems are translated into a structured problem set that is sufficiently well defined to entail specific research decisions and actions. Commonly, once the problems can be clearly defined and morphologically described, the characteristics of the process system that contains the identified problems can be taken into account. That is, a systems thinking approach is put forth to conceptually model the system characteristics that need to be studied and improved, the target improvement objectives should correspondingly be explicated. Like the cases studied in the research, the process performance investigated is tiered with the key competitive factors (e.g. the process cycle time for changing the fashion business environment).

Prior to the conceptualisation of the process system, the interdependency and organisation of process structure should be examined and documented as input data for subsequent analyses. Building the communicative model is the process of developing a set of communication model representations from the previous concept models. These communicative models allow experts and teams to discuss, compare and judge the process interpretively. Flowcharts, structured pseudocodes and the process interdependency graph and matrices are documented. While various forms of representative process models are constructed, there is also a need to develop executable programme models that aim at rationalising the model behaviour and predict potential impacts of changes on the entire process system. Pragmatically, most of the programmed models are simulation models and procedures, like the GA established in this thesis. When incorporated with activity process data, the models can be implemented to investigate the consequence of any change in the process system. Once the models are tested or appear to insufficiently improve the current status of the process system, verification of the nature of the process system and its characteristics is required before starting the investigation all over again. Such modelling iteration gives rise to a continuing process of verification, testing and validation for improving process structures. The results arising from the life cycle are accordingly updated and used to support enterprise decisions to improve the existing process systems and configurations, and to redesign the resource distribution to the respective activities within the specified systems.

It is reasonable to recognise the need for institutionalising the framework as a continuous learning process. Existing activity process design serves the market very well during periods of stable market conditions. However, when the market is dynamic and competition oriented, we must re-examine the process efficiency, build on distinctive process strengths and move onward to an agile process that can respond to market requirements in a proactive manner. Meanwhile, the activities across different enterprises aligned in a supply pipeline should be integrated strategically, as suggested in the concept framework presented in Chapter Five. Definitely, such alignment is not a single-attempt exercise in the process of choosing an appropriate activity process structure and associated integration mechanisms.

6.4 Future work

This thesis presents the themes pervading the research problem, the development of methodologies for capturing data and analysing the problem, and the generalisation of the use of the framework developed in the course of the research. Yet, all of these indicate a need for a great deal of follow-on research work.

6.4.1 A taxonomy of dependency in process design

This thesis concerns the management and co-ordination of interdependent activities. Dependency accounts for substantial impacts on planning and scheduling geographically dispersed activities. Dependency influences decisions and actions during the course of activity process. Dependency underlies repercussive consequences of change among interdependent activities. Dependency exhibits its significance for today's globalising activities. As illustrated in this thesis, the extant theoretic compendium of dependency is definitely insufficient for substantive discussions of today's activity process management and the analysis of process integration. In this thesis, different perspectives, descriptions, concept constructs, measures and analyses of dependency among business activities are included, underlying a foundation to develop a thorough taxonomy for discussing such a pertinent topic as dependency.

6.4.2 Qualitative reasoning of interdependency

Current development of dependency theories in process design have mainly stemmed from studies of engineering design, information science and organisation science and, in the majority, focus on the analysis aspects on a network basis. The strategies of these analyses are very quantitatively, or formally, treated. The real world network process is fuzzy, uncertain and ill-structured. There is a long existent niche to treat process analyses by applying approximations, i.e. qualitative methods to reason and predict process behaviour. The analyses of process performance should allow a certain extent of vagueness and indeterminacy. Originally it was planned, as a part of this research, to develop a qualitative reasoning procedure to analyse interactivity dependency from an artificial intelligence perspective, but this could not be achieved because of the constraints of resources and time. Academically observed, a start has been made for research communities to consider the further development of uncertainty-based activity process analyses and reasoning. Such types of research definitely pose many opportunities for decision making for global activities.

6.4.2 Modelling of virtual enterprises

As stated, this research falls into the compendium of virtual enterprising modelling and management. The results in this thesis support integration and diagnosis of interdependent activities that cross geographically dispersed enterprises. Integration of activity interaction carries the generic characteristics of contact directivity, periodicity, accessibility, synchronicity and so on. Dependency-based studies can aid in dissecting these characteristics and help management to choose appropriate types of integration approaches and mechanisms. As reiterated, the integration approaches concern different strategies to develop consistent interaction systems among teams and activities, either by information-centric or people-centric schemes. Integration mechanisms pragmatically relate to the facility enablers that maintain and promote integration in the course of business processes. Extant academic development in virtual enterprises stems mainly from information science and design. Yet, it can be developed from the novel perspective of dependency as is studied in this research.

6.4.4 Multi-attribute utility theories (MAUT) for innovation decisions

This thesis is successful at showing how the MAUT applies to assess the strength of interactivity dependency. MAUT is indeed a long established and sophisticated approach for addressing almost all the problems of strategic decision making. It is believed to be one of the most powerful tools to support smart decisions for novel problems, like development and implementation of innovative systems, choice of locations, preferred enterprises along a supply chain, etc. The economic nature of the whole Far East region of the world is radically transforming. International industry practitioners and even governments feel a strong need for reformulating the configuration of global production and supply operations, and their strategic alignment with different partners in the other economies.

MAUT can be adopted to evaluate the dependency among locations, either from an operational or a macroeconomic viewpoint. It is incumbent upon the research community to disseminate and apply the theories to industries and practising users. From the applied research viewpoint, MAUT-based dependency study is noteworthy.

All of these areas are ways in which dependency research and modelling can be extended. Certainly these underlie a field that provides ample opportunity to challenge research communities in coming years.

Appendix A: The Genetic Algorithm

A.1 Algorithmic Statement and Pseudocodes

This programme essentially contains two components. The first one is the objective function. It calculates the expected time span of activity planning cycle, given that various structures of interactivity dependency exist as some pairs of interdependent activities are decoupled. The objective function will be called frequently within the programme. The second component of the programme is the genetic algorithm (GA). It finds a nearly optimal mean of cycle time spans and its corresponding choice of activity pairs to be decoupled.

Component 1: The cycle time model

The relationships among activities (vertices) are represented in directional arcs. In specific pairs of activities, arcs starting only from upstream activities pointing to downstream activities are regarded as sequentially forward links. That is to say, downward activities, i, are "dependent" on upstream activities, j, such that $i<j$. In an analogous sense, arcs starting from downstream activities pointing back to upstream activities are backward links indicating the notion of backward dependence. Such relationships carry various extents of probability of process iteration initiating from downstream work processes. Pairs of vertices showing no arcs means that the activities are mutually independent. Such activities can be processed in parallel, without the constraint of sequencing order.

For vertices linked by both forward and backward arcs, circuits exist and express iterative workflow processes. In a pair of vertices $\{i,j\}$, such arcs form a loop wherein one activity is dependent on each other, i.e. implying the sense of interdependency. Once an activity fails or calls for process iteration, the other one should start simultaneously. In the cases we model, the arcs carry various weights. The objective of the problem is to find the expected minimum cycle times of alternative activity process paths through transforming the nature of links, i.e. truncating the nature of dependency among activities. The ways to transform the dependences refer to policies of the tearing scheme pre-determined by model users.

For the sake of representation simplicity, we reduce the arcs in each pair of two interdependent activities into a "bidirectional arc". Thus we begin with a graph with three kinds of arcs: forward arcs, backward arcs and bidirectional arcs.

Let all bidirectional arcs be indexed. A 'cut scheme' is the set of bidirectional arcs (the "cuts or tears") that we wish to transform. A bidirectional arc can be transformed into a forward arc, a backward arc or an "empty" arc (i.e., the arc is removed). Each way of transform corresponds to a decoupling of the relations between a pair of interdependent activities.

It's completely arbitrary on how a bidirectional arc should be transformed. In our program, we provide two cut policy options: either the bidirectional arcs are randomly selected within a pre-specified maximum number of cuts to be transformed into forward arcs, or the bidirectional arcs in all cuts are removed simultaneously using a random selection pattern.

For example, if we had 4 interdependent activity pairs (1,3), (1,4), (2,5), (3,4). Then we have 4 bidirectional arcs {1,3}, {1,4}, {2,5} and {3,4} which we index as arc 1 up to arc 4 respectively. Suppose the user chooses to remove bidirectional arcs. Then by performing a cut scheme, say, (1,3,4), we aim to remove arc 1, arc 3 and arc 4.

So, given a cut scheme, we first remove the links specified by the cuts from the original set of links between activities. Then we should identify all "deadlocks" in the remaining hierarchy, i.e., cycles that are composed of interdependent arcs and at least one forward arc. As all interdependent activities are required to start simultaneously, but the downstream activity of a forward arc can begin only after the upstream activity has finished, there is no way to begin the activities in a deadlock. Hence the programme will classify a cut scheme that causes deadlocks as 'not feasible' and invalidate all forward arcs in a deadlock. We follow the latter approach in the program.

Hence, given a cut scheme, we always end up with a hierarchy of activities that can work. Now the cycle time is calculated by simulation. The following are rules/constraints for the simulation:

(a) Each activity cannot begin if any of its upstream activities (connected by an incoming forward arc) have not finished.

(b) Each activity begins exactly when it and all its interdependent activities (connected to it by bidirectional arcs) do not violate the above condition.

(c) On completion of each activity process work (a trial), an activity has a pre-assigned probability, p(i), to fail or to call for upstream processes reworking. In our program, such probability on the n-th trial is the n-th power of some user-specified p(i) if $n<3$, and 0 otherwise.

(d) If an activity A fails to complete, it can attribute this failure to one of the activities that is joined from it by a backward arc or a bidirectional arc in random fashion.

(e) If the activity A above attributes its failure to activity B, all interdependent activities of B must restart. Also, all their downstream activities must stop if they are in progress or about to begin/end.

(f) The cycle time of the whole planning is taken as the time elapsed until all activities have finished.

(g) Learning factor

Suppose the duration of an activity A is 5 units and the duration of B is 2 units on first trials. Then their durations will change according to the number of times of completions (iterations) n*.

In general,

t(n*) = max[t(0) – n*, 1] if n*<3;

t(n*) = 1 if n* >= 3.

e.g. :

n*	0	1	2	3	4	5	6
A	5	4	3	1	1	1	1
B	2	1	1	1	1	1	1

The pseudocodes:

(1) Given that certain arcs are truncated, the following steps are initiated to update the length of the process cycle by Monto-carlo pattern.

(2) Given the mean cycle time with an absolute error at 2.5 to 97.5 % confidence to the most;

T := accumulated cycle time = 0;

n := number of iterations = 0;

do {

T=T + cycle time obtained by the simulation (below) in this iteration

n = n + 1

mean := the current mean cycle time = T/n

var := estimated variance of the mean = (T*T/n – mean*mean)/n

} while n <=30 or var .1.0/16;

The value of "mean" is returned as the expected cycle time

(3) The simulation:

S = set of schedulable activities

R = rules/constraint requirements

step 0 at the completion of an activity i at time t, update the time status and activity status in set S. Determine the latest finish time, latest start time, duration for each of these activities at time t;

step 1 check if it is feasible to schedule all activities in set S according to the rules/constraints. If yes, schedule all activities in set S and move to the next time instant. Otherwise, construct a graph and obtain all feasible subsets of set S until the rules/constraints are satisfied;

step 2 determine the value of t*, next time instant for scheduling for each subset corresponding to each terminal vertex and evaluate the value of objective function in terms of the function E := Σ max (t* - latest start of activity I, 0) ;

step 3 schedule activities in subset S* for which the value E is minimum. If more than one set has the same value of the objective function, then break the tie by selecting the set with the set with max number of activities. Set the new value of t to t* corresponding to the subset selected, S*. Go to *step 0.*

Component 2: The Genetic Algorithm

The program uses a Genetic Algorithm (GA) to find a cut scheme under which expected time span of a planning cycle is believed to be nearly-optimal. The mean cycle time under a cut scheme is found by repeated simulations. In each iteration a new cycle time will be taken and the mean cycle time will be updated. The iteration stops if we are 95% confident (using the Central Limit Theorem) that the mean cycle time obtained so far differs from the true one only by at most 0.5.

The GA itself is a "flavor" (namely, a steady state GA) of the many different kinds of GA. The pseudocodes are described below, where we use the following notations:

N := total number of interdependent pairs;
M := the maximum number of links between the interdependent activities that one can break.

2.1 The GA operations:

initialize (2.2) the population (whose size is pre-specified);
iterate the following for a pre-specified number of times:
do {
1) form a mating pool by reproducing (2.3) cut schemes from the population; the size of the mating pool is a pre-specified percentage of the population size;
2) from the mating pool, pair up cut schemes at random, and perform on each pair a crossover (2.4) with a pre-specified probability;
3) mutate (2.5) each cut scheme in the mating pool with a pre-specified probability;
4) merge the mating pool and the population, then return the new population to its original size by removing the worst individuals;
}

Then the cut scheme with the best cycle time is our optimal one.

2.2 Initialization of GA

First cut scheme in the population should be empty (contain no cuts). The rests are initialized by choosing at random a number of cuts between 0 and M.

2.3 Reproduction

Cut schemes in the population are selected at random and are copied to the mating pool. An individual has a probability p of being chosen if p is equal to the fitness of the individual divided by the sum of the fitness' of all individuals in the population. The fitness F of a cut scheme associated with mean cycle time t is defined as F = a*(T-t)+b*s, where s is the standard deviation of the mean cycle times associated with the cut schemes in the population, T is the maximum expected cycle time among the population, and a>0, b>=0 are two pre-specified numbers.

2.4 Crossover

Shuffle at random the non-overlapping cuts between the mating schemes, while keeping the number of cuts in each scheme unchanged. Example:

before crossover-- scheme1 = {23, 56, a, b, c, d}, scheme2 = {23, 56, e, f};

after crossover -- scheme1 = {23, 56, g, h, i, j}, scheme2 = {23, 56, k, l},

where a, b, ..., f are distinct and {g, h, ..., l} = {a, b, ..., f}.

2.5 Mutation

If the current cut scheme has n cuts -- we say that it is in state n -- it can mutate/transit to state n-1 (erase one cut at random), state n (add one cut and then erase one cut at random) or state n+1 (add one cut at random) with the following transition probabilities:

n->n+1 with probability (1 - n/N)r if n<M;

n->n+1 with probability 0 if n=M;

n->n-1 with probability (n/N)r if n>0;

n->n-1 with probability 0 if n=0;

n->n with probability 1 - prob(n->n-1) - prob(n->n+1);

where 0<r<1 is a pre-specified "transition rate".

A.2 C++ Header files

```
#ifndef COMMON_CONSTRUCTS_H
#define COMMON_CONSTRUCTS_H

#include <boost/graph/adjacency_list.hpp>
struct Item
{
  int actv_num;      // should be integer
  int serv_time;     // should be positive integer
  double fail_prob;    // double in [0,1)
};

typedef boost::adjacency_list<boost::vecS, boost::vecS, boost::directedS,
  boost::no_property, boost::property<boost::edge_weight_t, int> > Digraph;
struct EdgeFlex
{
  EdgeFlex();
  EdgeFlex(int source, int target, int f) : s(source), t(target), flex(f) {}
  int s;
  int t;
  int flex;
};

#endif
```

```
#ifndef DEPENDENCY_H
#define DEPENDENCY_H

#include <map>
#include <vector>
#include <utility>   // for std::pair
#include <boost/graph/adjacency_list.hpp>
#include "common_constructs.h"
#include <string>

struct Dependency
{
  typedef boost::adjacency_list<boost::vecS, boost::vecS, boost::directedS,
    boost::no_property, boost::property<boost::edge_weight_t, int> > Digraph;

  Dependency() {}

  // Initialization
  //---------------
  void init_by(std::vector<Item> const & items, std::vector<EdgeFlex> const & edge_flex_list,
                              std::vector<int> & duplicated_activities,
                              std::vector<EdgeFlex> & nonexist_destinations,
                              std::vector<EdgeFlex> & inconsistent_weights);

  // Total number of activities
  //---------------------------
  int num_activities() const {return num_activities_;}

  // Choose those married arcs whose weights are >= w, store them into
  // the filtered_deges constainer, and return the size of the container
  //-------------------------------------------------------------------
  int filter_ge(std::vector<Digraph::edge_iterator> & filtered_edges, int w) const;

  // Store the distribution of weights of married_arcs
  //-------------------------------------------------
  void store_weight_distribution(std::map<int, int> & wdist) const;

  // Find the minimum and maximum weights of the married_arcs
  //-------------------------------------------------------
  std::pair<int, int> find_min_max_weights() const;
```

```
    std::map<int, int>   index;
    std::vector<int>      actv_num;
    Digraph   self_loops;      // containing all self-loops
    Digraph   married_arcs;   // containing all arcs (a,b) such that (b,a) exists and a<b
    Digraph   single_fwds;     // containing forward-only arcs (for checking feasibility)
    Digraph   single_bwds;     // containing backward-only arcs (for checking feasibility)

  private:
    int num_activities_;        // number of activities
  };

  #endif
```

```
#ifndef EVOLVE_H
#define EVOLVE_H

#include "dependency.h"
#include <string>

// The following ifdef block is the standard way of creating macros which make exporting
// from a DLL simpler. All files within this DLL are compiled with the EVOLVE_EXPORTS
// symbol defined on the command line. this symbol should not be defined on any project
// that uses this DLL. This way any other project whose source files include this file see
// EVOLVE_API functions as being imported from a DLL, wheras this DLL sees symbols
// defined with this macro as being exported.
#ifdef EVOLVE_EXPORTS
#define EVOLVE_API __declspec(dllexport)
#else
#define EVOLVE_API __declspec(dllimport)
#endif

struct AllParameters
{
  enum CUT_POLICY {break_one, break_both};

  long N0;           // total number of activity pairs
  long wMin;         // minimum arc weight
  long wMax;         // maximum arc weight
  long weight;     // threshold weight
  long N1;           // total number of breakable pairs
  long mCuts;      // maximum number of cuts
  CUT_POLICY how_to_break;
  long popuSize; // population size
  long nGen;        // number of generations
  double pRepl;   // percentage of replacement
  double pMut;     // mutation rate
  double pCross; // crossover rate

  std::vector<Item> items;
  Digraph edge_flex_graph;
  std::vector<std::vector<double> > proximity;
  Dependency dependency;
  std::string stat_filename;
  std::string genInfo_filename;
};

struct OutputDevice
{
  virtual void output(std::string const & message) {}
};

EVOLVE_API void evolve(AllParameters const & param, OutputDevice * pDevice);

#endif
```

```
#ifndef LINKGENOME_H
#define LINKGENOME_H

// In the following, we define a genome class for holding a bit (or boolean) string so
// that at most some (prescribed by a user-input number) of them can be 1 (or true).

#include <ga/GAGenome.h>
#include <list>
#include <iostream.h>
#include "random.h"

class LinkGenomeOperators;

// Class definition for the new genome object, including statically defined
// declarations for default evaluation, initialization, mutation, and
// comparison methods for this genome class.
class LinkGenome : public GAGenome
{
  friend class LinkGenomeOperators;

public:
  // CLASS FUNCTIONS MAINLY TO SUPPORT GAGenome
  GADefineIdentity("LinkGenome", 201);
  static void Init(GAGenome&);
  static int Mutate(GAGenome&, float);
  static float Compare(const GAGenome&, const GAGenome&);
  static float Evaluate(GAGenome&);
  static int Cross(const GAGenome&, const GAGenome&, GAGenome*, GAGenome*);

  // CLASS FUNCTIONS SPECIFIC TO THIS CLASS
  static void set(int numLinks, int maxNumCuts) {nLinks = numLinks; mCuts = maxNumCuts;}

  // INSTANCE FUNCTIONS MAINLY TO SUPPORT GAGenome
  LinkGenome() : GAGenome(Init, Mutate, Compare)
  {
    evaluator(Evaluate);
    crossover(Cross);
  }
  LinkGenome(const GAGenome& orig) { copy(orig); }
  virtual ~LinkGenome() {}
  LinkGenome& operator=(const GAGenome& orig)
  {
    if(&orig != this) copy(orig);
    return *this;
  }
  virtual GAGenome* clone(CloneMethod) const {return new LinkGenome(*this);}
  virtual void copy(const GAGenome& orig)
  {
    GAGenome::copy(orig);   // this copies all of the base genome parts
    // copy any parts of LinkGenome here
    cutPos = (static_cast<const LinkGenome&>(orig)).cutPos;
  }
  virtual int equal(const GAGenome&) const;
  virtual int write (ostream& os) const;

  // INSTANCE FUNCTIONS/MEMBERS SPECIFIC TO THIS CLASS
  void   setToIdentity();
  float getScore() {return _score;}
  std::list<int> cutPos;      // the cut positions

//private:
  static RandomGenerator rng;
  static int nLinks;            // number of links
  static int mCuts;              // maximum allowable number of cuts
  static float lambda;          // parameter for mutation
};

class LinkGenomeOperators
```

```
{
protected:
   static void set_evaluated(LinkGenome & g, _GABoolean TF) {g._evaluated = TF;}
};

#endif
```

```
#ifndef OBJ_CYCLE_TIME_H
#define OBJ_CYCLE_TIME_H

#include <fstream.h>
#include <vector>
#include <boost/graph/adjacency_list.hpp>
#include "evolve.h"
#include "LinkGenome.h"
#include "random.h"

class Obj_cycle_time
{
public:
   typedef AllParameters::CUT_POLICY CUT_POLICY;

   static void set_output_device(OutputDevice * pDev) { pDevice = pDev; }
   static void set(Dependency const &, std::vector<Item> const &, int w);
   static void set_cut_policy(CUT_POLICY p) {how_to_break = p;}
   static float value(GAGenome &);
   static void write(const LinkGenome & g, ostream& os);

private:
   typedef boost::adjacency_list<boost::vecS, boost::vecS, boost::directedS> Graph;
   typedef Graph::adjacency_iterator AdjacencyIterator;
   typedef Graph::vertex_descriptor   Vertex;
   typedef Graph::edge_descriptor      Edge;
   typedef Graph::edge_iterator        EdgeIterator;

   struct Node
   {
      enum Message {NONE, REDO, CANCEL, COLLECT};
      enum Status {WAITING, VALIDATING, BEGIN, IN_PROGRESS, FINISH, COMPLETED};

      int                          max_num_trials;
      int                          max_num_complaints;
      int                          time_length_on_first_trial;
      int                          time_length;
      float                        failure_prob;

      int                          num_trials;
      int                          num_complaints;
      Message                      msg_received;
      Status                       status;
      int                          time_to_completion;

      bool succeed_to_begin();
      bool succeed_to_complete();
      static RandomGenerator       rng;
   };

   static OutputDevice *          pDevice;
   static const Dependency *      dependency;
   static std::vector<Dependency::Digraph::edge_iterator> filtered_edges;
   static RandomGenerator         rng;

   static std::vector<Node>       activity;
   static Graph targetF_r0Z;
   static Graph sourceF_r0Z;
   static Graph targetI_r;
   static Graph targetF;
```

```
    static Graph sourceF_r1;
    static Graph targetBI;
    static std::vector<std::vector<int> > distance;

    //static std::vector<Edge> removed_from_I;
    //static std::vector<Edge> added_to_F;
    //static std::vector<Edge> removed_from_F;
    //static std::vector<Edge> removed_from_FI;
    static CUT_POLICY      how_to_break;   // break one arc or both in a cut

    static void restructure_graph_with(const LinkGenome &);
    static void initialize_activities();
    static void preprocess();
    static void step();
    static void postprocess();
    static bool not_completed();

    static void clear_all_msg();
    static void notifyRedo(int a)        { activity[a].msg_received = Node::REDO; }
    static void notifyCancel(int a)      { activity[a].msg_received = Node::CANCEL; }
    static void notifyCollect(int a)     { activity[a].msg_received = Node::COLLECT; }
    static bool isReady(int a);
    static int   randomUpDestination(int a);

//#ifdef _DEBUG
public:
    static void print_status(ostream &);
    static void print_msg(ostream &);
    static void print_graphs(ofstream & output);
private:
    static void print_graph(Graph const & g, ofstream & output);
//#endif
};

#endif
```

```
ifndef PARAM_H
#define PARAM_H

/*
// For compilers that support precompilation, includes "wx/wx.h".
#include "wx/wxprec.h"

#ifdef __BORLANDC__
#pragma hdrstop
#endif

// for all others, include the necessary headers (this file is usually all you
// need because it includes almost all "standard" wxWindows headers)
#ifndef WX_PRECOMP
#include "wx/wx.h"
#endif
*/

#include "wx/string.h"
#include "../read_excel/read_excel.h"
#include "evolve.h"
#include <fstream>

struct Param : public AllParameters
{
    wxString N0Str, wMinStr, wMaxStr, weightStr, N1Str, mCutsStr, popuSizeStr, nGenStr, pReplStr,
pMutStr, pCrossStr;

    std::string excel_filename;
    std::vector<Error> error_info;
    std::string fatal_error;
```

```
    std::vector<wxString> errors;
    std::vector<wxString> warnings;

    void ClearMessages();
    void ValidateFilenames();
    void ValidateWeight();
    void ValidateGenomeParameters();
    void ValidateGAParameters();
    void FindNumActivityPairsAndMinMaxWeight();
    void FindNumFilteredBreakablePairs();
    void Evolve(OutputDevice *);

/*
    void write_actv_num(std::ofstream & mapping);
    // File "arcs_flex.txt"
    // The file contains the total number of activities, followed by the
    // source and destination of each arc and the corresponding
    // flexibility line by line. NO REPEATED EDGES ARE ALLOWED.
    // Example:
    // 6
    // 1   4   0
    // 2   3   0
    // 3   5   1
    // 3   2   5

    void write_time_prob(std::ofstream & time_prob);
    // File "mapping.txt"
    // Contains the activity numbers of the activities (in the order of
    // appearance in the original data sheet).
    // Example:
    // 1
    // 2
    // 4
    // 7
    // 8
    // 10

    void write_arcs(std::ofstream & arcs_flex);
    // File "time_prob.txt"
    // Each row contains the service time and failure probability of the corresponding activity.
    // Example:
    // 1   0.1
    // 2   0
    // 5   0.14
    // 3   0.2
    // 3   0.05
    // 1   0.0001

    void write_proximity_table(std::ofstream & proximity_table);
    // File "proximity.txt"
    // Format of input file. Suppose there are n activities, say, activities 1, ..., n.
    // Let p(a,b) be the proximity between activity a and activity b. Then the input file
    // should contain n(n-1)/2 entries in the following layout:
    // p(2,1)
    // p(3,1)   p(3,2)
    // p(4,1)   p(4,2)   p(4,3)
    // ...
    // p(n,1)   p(n,2)   p(n,3) ... p(n,n-1)
*/
};

#endif


#ifndef RANDOM_H
#define RANDOM_H

#include <math.h>
```

```
/*--------------------------------------------------------------------------
   Unform Random Number Generator
   ---------------------------------------------------------------------------*/
class RandomGenerator
{
public:
      RandomGenerator(double l = 0, double u = 1);
      virtual ~RandomGenerator() {};
      virtual double   Rand();
      void              Reset();
      void              SelectSeed(long int seed);
   long int         GetSeed() const;
private:
      long int          current_seed;
      long int          base_seed;
      double              L;
      double              U;
      double              range;
};
// Constants
const double MODULUS = 2147483647.0L;       // 2^31 - 1 =   2,147,483,647
const double A_100000 = 241748845.0L;      // A^100000 mod MODULUS
const double A = 62089911.0L;              // From reference

inline RandomGenerator::RandomGenerator(double l, double u)
      : base_seed(1000), L(l), U(u) {current_seed = base_seed; range = U - L;}

inline double RandomGenerator::Rand()
{   current_seed = (long int)fmod((double)current_seed * A, MODULUS);
      return L + range * (double)current_seed / MODULUS;
}
inline void RandomGenerator::SelectSeed(long int seed) { base_seed = seed; }
inline void RandomGenerator::Reset() { current_seed = base_seed; }
inline long int RandomGenerator::GetSeed() const { return current_seed; }
#endif




// ---------------------------------------------------------------------------
// headers
// ---------------------------------------------------------------------------
#ifdef __GNUG__

#pragma implementation "winmain.cpp"
#pragma interface "winmain.cpp"
#endif

// For compilers that support precompilation, includes "wx/wx.h".
#include "wx/wxprec.h"

#ifdef __BORLANDC__
#pragma hdrstop
#endif

// for all others, include the necessary headers (this file is usually all you
// need because it includes almost all "standard" wxWindows headers)
#ifndef WX_PRECOMP
#include "wx/wx.h"
#endif

#include "wx/notebook.h"
#include "param.h"
#include <vector>

// ---------------------------------------------------------------------------
// private classes
// ---------------------------------------------------------------------------
```

```
class SettingPage;
class ErrorPage;
class OutputPage;
class MyNotebook;

bool FileReadable(wxWindow * parent, wxString & finename, wxString const &prefix = "File ");
bool FileWritable(wxWindow * parent, wxString & finename, wxString const &prefix = "File ");

class StepPanel : public wxPanel
{
public:
    wxPanel    *m_config_panel;
    wxButton *m_back;
    wxButton *m_next;
    wxButton *m_exit;

    StepPanel(wxWindow* parent, wxWindowID id, Param & p);
    virtual void LazyInit(int i) = 0;
    virtual void OnNext() = 0;
    virtual void OnReset() = 0;

protected:
    //DECLARE_EVENT_TABLE()
    Param & param;
};

class BrowseFilePanel : public StepPanel
{
public:
    BrowseFilePanel(wxWindow* parent, wxWindowID id, Param & p);
    void LazyInit(int i);
    void OnChooseExcel(wxCommandEvent& event);
    void OnChooseStat(wxCommandEvent& event);
    void OnChooseGenInfo(wxCommandEvent& event);
    bool Show(bool TF);
    void OnNext();
    void OnReset();

    bool excel_filename_verified;
    bool stat_filename_verified;
    bool genInfo_filename_verified;
    wxTextCtrl *text_ctrl_excel;
    wxTextCtrl *text_ctrl_stat;
    wxTextCtrl *text_ctrl_genInfo;
    wxString program_path;
    wxString excel_path;
    wxString stat_path;
    wxString genInfo_path;

private:
    DECLARE_EVENT_TABLE()
};

class FilterByWeightPanel : public StepPanel
{
public:
    FilterByWeightPanel(wxWindow* parent, wxWindowID id, Param & p);
    void LazyInit(int i);
    bool Show(bool TF);
    void OnNext();
    void OnReset();

    wxStaticText *label_total;
    wxStaticText *label_range;
    wxTextCtrl *text_ctrl_weight;    // min. flexibility for breaking a pair

private:
    //DECLARE_EVENT_TABLE()
```

```
};

class GenomeParametersPanel : public StepPanel
{
public:
    GenomeParametersPanel(wxWindow* parent, wxWindowID id, Param & p);
    void LazyInit(int i);
    bool Show(bool TF);
    void OnNext();
    void OnReset();

    wxStaticText *label_newTotal;
    wxTextCtrl *text_ctrl_mCuts;
    //wxRadioButton *radio_button_cutOne;
    //wxRadioButton *radio_button_cutBoth;
    wxRadioBox *radio_box;

private:
    //DECLARE_EVENT_TABLE()
};

class GAParametersPanel : public StepPanel
{
public:
    GAParametersPanel(wxWindow* parent, wxWindowID id, Param & p);
    void LazyInit(int i);
    bool Show(bool TF);
    void OnNext();
    void OnReset();

    wxTextCtrl *text_ctrl_popuSize;
    wxTextCtrl *text_ctrl_nGen;
    wxTextCtrl *text_ctrl_pRepl;
    wxTextCtrl *text_ctrl_pMut;
    wxTextCtrl *text_ctrl_pCross;

private:
    //DECLARE_EVENT_TABLE()
};

class SettingPage : public wxPanel
{
public:
    std::vector<StepPanel *> step;

    SettingPage(wxWindow* parent, wxWindowID id, Param & p);
    virtual MyNotebook* GetParent() const;
    void LazyInit(Param & p);
    void OnBack(wxCommandEvent& event);
    void OnNext(wxCommandEvent& event);
    void OnReset(wxCommandEvent& event);
    int CurrPanelIndex() {return curr_panel_index;}

private:
    DECLARE_EVENT_TABLE()
    int curr_panel_index;
    Param & param;
};

class ErrorPage : public wxPanel
{
public:
    wxTextCtrl    *cerr;
    wxButton      *m_save;
    ErrorPage(wxWindow* parent, wxWindowID id, Param & p);
    void OnSave(wxCommandEvent& event);
    void ClearConsole();
    void ShowErrorMessages();
private:
```

```
    DECLARE_EVENT_TABLE()
    Param & param;
};

class OutputPage : public wxPanel, public OutputDevice
{
public:
    wxTextCtrl    *cout;
    OutputPage(wxWindow* parent, wxWindowID id, Param & p);
    void ClearConsole();
    void output(std::string const &);
private:
    //DECLARE_EVENT_TABLE()
};

class MyNotebook : public wxNotebook
{
public:
    SettingPage *setting_page;
    ErrorPage     *error_page;
    OutputPage    *output_page;

    MyNotebook(wxWindow *parent, wxWindowID id, Param & p);
    void ClearConsoles();
    void ShowErrorMessages();
    OutputDevice * ShowOutput();

private:
    //DECLARE_EVENT_TABLE()
    Param & param;
};

class MyFrame : public wxFrame
{
public:
    MyNotebook * notebook;

    MyFrame(const wxString& title, const wxPoint& pos, const wxSize& size, Param & p);

    // event handlers (these functions should _not_ be virtual)
    void OnExit(wxCommandEvent& event);

private:
    //DECLARE_EVENT_TABLE()
};

class MyApp : public wxApp
{
public:
    // override base class virtuals
    // ----------------------------

    // this one is called on application startup and is a good place for the app
    // initialization (doing it here and not in the ctor allows to have an error
    // return: if OnInit() returns false, the application terminates)
    virtual bool OnInit();

private:
    Param param;
};

// ----------------------------------------------------------------------------
// constants
// ----------------------------------------------------------------------------

// IDs for the controls and the menu commands
enum
{
    // StepPanel buttons
```

```
    StepPanel_Back = 1,
    StepPanel_Next,
    StepPanel_Reset,
    ErrorPage_Save,
    Button_ChooseExcel,
    Button_ChooseStat,
    Button_ChooseGenInfo,
    Button_CutOne,
    Button_CutBoth,
};


#ifndef READ_EXCEL_H
#define READ_EXCEL_H

#include <vector>
#include <string>
#include "../include/common_constructs.h"

// The following ifdef block is the standard way of creating macros which make exporting
// from a DLL simpler. All files within this DLL are compiled with the READ_EXCEL_EXPORTS
// symbol defined on the command line. this symbol should not be defined on any project
// that uses this DLL. This way any other project whose source files include this file see
// READ_EXCEL_API functions as being imported from a DLL, wheras this DLL sees symbols
// defined with this macro as being exported.
#ifdef READ_EXCEL_EXPORTS
#define READ_EXCEL_API __declspec(dllexport)
#else
#define READ_EXCEL_API __declspec(dllimport)
#endif
/*
struct READ_EXCEL_API Item
{
   int actv_num;      // should be integer
   int serv_time;     // should be positive integer
   double fail_prob;     // double in [0,1)
};

struct READ_EXCEL_API EdgeFlex
{
   EdgeFlex();
   EdgeFlex(int source, int target, int f) : s(source), t(target), flex(f) {}
   int s;
   int t;
   int flex;
};
*/
struct READ_EXCEL_API Error
{
   enum ErrorType
   {
     INVALID_FORMAT, Z_EXPECTED, N_EXPECTED, GE0_LT1_EXPECTED,
NON_NEG_REAL_EXPECTED,
       INVALID_ACTV_NUM, SELF_LOOP, INCONSISTENT_WEIGHTS,
NUM_ERROR_TYPES
   };
   Error(int i, int j, ErrorType e);
   std::string str() const;
   bool operator<(Error const & error) const;

   int i, j;
   ErrorType e;
};

class READ_EXCEL_API ExcelFileValidator
{
public:
   ExcelFileValidator(
```

```
                  std::vector<Item> & items_,
                  Digraph & edge_flex_graph_,
                  std::vector<std::vector<double> > & proximity_,
                  std::vector<Error> & errors_,
                  std::string & fatal_error_);
  void input(std::string const & excel_filename);

 private:
  std::vector<Item> & items;
  Digraph & edge_flex_graph;
  std::vector<std::vector<double> > & proximity;
  std::vector<Error> & errors;
  std::string & fatal_error;
};

#endif

// stdafx.h : include file for standard system include files,
//  or project specific include files that are used frequently, but
//       are changed infrequently
//

#if !defined(AFX_STDAFX_H__E9E93502_22A2_11D5_9448_00010256DBE7__INCLUDED_)
#define AFX_STDAFX_H__E9E93502_22A2_11D5_9448_00010256DBE7__INCLUDED_

#if _MSC_VER > 1000
#pragma once
#endif // _MSC_VER > 1000


// Insert your headers here
#define WIN32_LEAN_AND_MEAN          // Exclude rarely-used stuff from Windows headers

//#include <windows.h>

// TODO: reference additional headers your program requires here
#include <Afx.h>
#include <odbcinst.h>
#include <Afxdb.h>
#include <sstream>
#include <boost/regex.hpp>

//{{AFX_INSERT_LOCATION}}
// Microsoft Visual C++ will insert additional declarations immediately before the previous line.

#endif
// !defined(AFX_STDAFX_H__E9E93502_22A2_11D5_9448_00010256DBE7__INCLUDED_)
```

A.3 Extracted results of GA evaluation

SSS_result 1_0_10

100 # current generation
1 # current convergence
11000 # number of selections since initialization
8278 # number of crossovers since initialization
161 # number of mutations since initialization
11000 # number of replacements since initialization
8539 # number of genome evaluations since initialization
101 # number of population evaluations since initialization
86.2957 # maximum score since initialization
53.8673 # minimum score since initialization
56.1064 # average of all scores ('on-line' performance)
56.385 # average of maximum scores ('off-line' performance)
55.2069 # average of minimum scores ('off-line' performance)

66.4372 # mean score in initial population
86.2957 # maximum score in initial population
60.3125 # minimum score in initial population
6.09691 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

53.8673 # mean score in current population
53.8673 # maximum score in current population
53.8673 # minimum score in current population
6.11743e-005 # standard deviation of current population
-1 # diversity of current population (0–identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiements GUI-iterative learning2 data_21\sss_gen1_0_10.txt # name of file to which scores are written

Total number of interdependant pairs: 59
Maximum number of links to break: 10
Time elasped = 2007.22
Original: 63.9709
Best: 53.8673
(12, 10) (15, 14) (20, 12) (21, 15) (40, 30) (70, 59) (77, 37) (95, 92)
(95, 93) (102, 101)
Worst: 86.2957
(38, 27) (39, 38) (40, 30) (46, 27) (49, 47) (50, 46) (52, 43) (56, 54)
(62, 44) (78, 34)

SSS-result1_1_10

100 # current generation
1 # current convergence
10000 # number of selections since initialization
7314 # number of crossovers since initialization
158 # number of mutations since initialization
10000 # number of replacements since initialization
7555 # number of genome evaluations since initialization
101 # number of population evaluations since initialization
83.7567 # maximum score since initialization
56.6437 # minimum score since initialization
58.013 # average of all scores ('on-line' performance)
58.2197 # average of maximum scores ('off-line' performance)
57.3411 # average of minimum scores ('off-line' performance)

67.2263 # mean score in initial population
83.7567 # maximum score in initial population
61.0107 # minimum score in initial population
6.29698 # standard deviation of initial population
-1 # diversity of initial population (0 identical,-1=unset)

56.6436 # mean score in current population
56.6437 # maximum score in current population
56.6437 # minimum score in current population
9.94331e-005 # standard deviation of current population
-1 # diversity of current population (0–identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiements\GUI-iterative learning2\data_21\sss_gen1_1_10.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 10
Time elasped = 1713.67
Original: 63.9112
Best: 56.6437
(12, 10) (15, 14) (20, 12) (21, 15) (33, 24) (70, 59) (77, 37) (90, 82)
(95, 92) (95, 93)
Worst: 83.7567
(12, 10) (21, 15) (26, 24) (63, 52) (72, 31) (78, 34) (95, 91)

SSS_result1_1_15

100 # current generation
1 # current convergence
12600 # number of selections since initialization
9304 # number of crossovers since initialization
183 # number of mutations since initialization
12500 # number of replacements since initialization
9610 # number of genome evaluations since initialization
101 # number of population evaluations since initialization
100.793 # maximum score since initialization
56.2203 # minimum score since initialization
57.5309 # average of all scores ('on-line' performance)
57.8102 # average of maximum scores ('off-line' performance)
56.6447 # average of minimum scores ('off-line' performance)

68.6621 # mean score in initial population
100.793 # maximum score in initial population
59.7937 # minimum score in initial population
7.4321 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

56.2204 # mean score in current population
56.2203 # maximum score in current population
56.2203 # minimum score in current population
0.000160539 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiecments\GUI-iterative learning2\data_21\sss_gen1_1_15.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 15
Time elasped = 2681.83
Original: 63.6314
Best: 56.2203

(12, 10)	(15, 14)	(20, 12)	(21, 15)	(42, 41)	(46, 27)	(49, 47)	(54, 48)
(67, 64)	(70, 59)	(72, 31)	(77, 37)	(90, 82)	(95, 92)	(95, 93)	

Worst: 100.793

(13, 12)	(22, 14)	(26, 25)	(29, 26)	(30, 25)	(34, 24)	(46, 27)	(50, 46)
(54, 34)	(54, 48)	(54, 53)	(77, 37)	(90, 82)			

SSS_result_1_1_20

100 # current generation
1 # current convergence
10000 # number of selections since initialization
7432 # number of crossovers since initialization
147 # number of mutations since initialization
10000 # number of replacements since initialization
7669 # number of genome evaluations since initialization
101 # number of population evaluations since initialization
98.2139 # maximum score since initialization
55.8409 # minimum score since initialization
57.4134 # average of all scores ('on-line' performance)
57.7404 # average of maximum scores ('off-line' performance)
56.5712 # average of minimum scores ('off-line' performance)

70.3146 # mean score in initial population
98.2139 # maximum score in initial population
60.8385 # minimum score in initial population
8.38765 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

55.8408 # mean score in current population
55.8409 # maximum score in current population
55.8409 # minimum score in current population
6.88369e-005 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiements\GUI-iterative learning2\data_21\sss_gen1_1_20.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 20
Time elasped = 2400.09
Original: 63.5386
Best: 55.8409

(12, 10)	(15, 14)	(20, 12)	(21, 15)	(26, 25)	(30, 25)	(33, 24)	(34, 24)
(38, 27)	(42, 41)	(49, 47)	(52, 43)	(54, 48)	(67, 64)	(70, 59)	(72, 31)
(77, 37)	(90, 82)	(95, 92)	(95, 93)				

Worst: 98.2139

(13, 12)	(18, 13)	(26, 24)	(29, 28)	(30, 25)	(33, 24)	(34, 24)
(38, 27)	(46, 27)	(50, 45)	(54, 48)	(58, 57)	(64, 54)	(81, 77)

SSS_result1_1_25

100 # current generation
1 # current convergence
7600 # number of selections since initialization
5679 # number of crossovers since initialization
108 # number of mutations since initialization
7500 # number of replacements since initialization
5857 # number of genome evaluations since initialization
101 # number of population evaluations since initialization
100.83 # maximum score since initialization
54.0155 # minimum score since initialization
56.2181 # average of all scores ('on-line' performance)
56.598 # average of maximum scores ('off-line' performance)
55.1547 # average of minimum scores ('off-line' performance)

71.1452 # mean score in initial population
100.83 # maximum score in initial population
61.6169 # minimum score in initial population
8.64825 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

54.0156 # mean score in current population
54.0155 # maximum score in current population
54.0155 # minimum score in current population
5.35847e-005 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiements\GUI-iterative learning2\data_21\sss_gen1_1_25.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 25
Time elasped = 1565.92
Original: 63.9112
Best: 54.0155

(12, 8)	(12, 10)	(13, 12)	(18, 13)	(18, 14)	(20, 12)	(21, 15)	(22, 14)
(29, 28)	(33, 24)	(42, 41)	(44, 39)	(46, 27)	(49, 47)	(53, 50)	(54, 48)
(58, 57)	(67, 64)	(70, 59)	(72, 31)	(77, 37)	(81, 77)	(90, 82)	(95, 92)
(95, 93)							

Worst: 100.83

(15, 14)	(21, 17)	(22, 14)	(29, 28)	(30, 24)	(30, 25)	(34, 24)	(46, 28)
(49, 47)	(52, 43)	(54, 34)	(54, 53)	(56, 54)	(70, 59)	(81, 77)	(83, 77)
(90, 82)	(95, 91)	(95, 92)					

SSS_result1_1_30

120 # current generation
1 # current convergence
15120 # number of selections since initialization
11245 # number of crossovers since initialization
229 # number of mutations since initialization
15000 # number of replacements since initialization
11552 # number of genome evaluations since initialization
121 # number of population evaluations since initialization
100.609 # maximum score since initialization
54.0158 # minimum score since initialization
55.6632 # average of all scores ('on-line' performance)
56.0209 # average of maximum scores ('off-line' performance)
54.7695 # average of minimum scores ('off-line' performance)

72.167 # mean score in initial population
100.609 # maximum score in initial population
59.5481 # minimum score in initial population
8.45199 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

54.0157 # mean score in current population
54.0158 # maximum score in current population
54.0158 # minimum score in current population
0.000107026 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiements GUI-iterative learning2\data_21\sss_gen1_1_30.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 30
Time elasped = 2422.47
Original: 63.828
Best: 54.0158

(12, 8)	(12, 10)	(13, 12)	(15, 14)	(18, 13)	(18, 14)	(20, 12)	(21, 15)
(21, 17)	(22, 14)	(26, 24)	(29, 26)	(30, 24)	(33, 24)	(34, 24)	(42, 41)
(49, 47)	(50, 45)	(52, 43)	(52, 46)	(53, 50)	(54, 34)	(54, 48)	(56, 54)
(70, 59)	(72, 31)	(77, 37)	(90, 82)	(95, 92)	(95, 93)		

Worst: 100.609

(13, 12)	(20, 12)	(22, 14)	(26, 24)	(26, 25)	(29, 26)	(29, 28)	(30, 25)
(33, 24)	(46, 27)	(47, 43)	(52, 43)	(54, 34)	(54, 48)	(56, 54)	(58, 54)
(58, 57)	(67, 64)	(70, 59)	(72, 31)	(78, 34)	(83, 77)	(95, 91)	(95, 92)
(95, 93)							

SSS_result2_0_10

100 # current generation
1 # current convergence
11000 # number of selections since initialization
8286 # number of crossovers since initialization
164 # number of mutations since initialization
11000 # number of replacements since initialization
8546 # number of genome evaluations since initialization
101 # number of population evaluations since initialization
84.4801 # maximum score since initialization
54.7439 # minimum score since initialization
56.422 # average of all scores ('on-line' performance)
56.6672 # average of maximum scores ('off-line' performance)
55.6187 # average of minimum scores ('off-line' performance)

66.2271 # mean score in initial population
84.4801 # maximum score in initial population
60.587 # minimum score in initial population
5.58436 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

54.7439 # mean score in current population
54.7439 # maximum score in current population
54.7439 # minimum score in current population
3.05872e-005 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiements\GUI-iterative learning2\data_21 sss_gen2_0_10.txt # name of file to which scores are written

Total number of interdependant pairs: 59
Maximum number of links to break: 10
Time elasped = 1935.38
Original: 63.7337
Best: 54.7439

(12, 10)	(15, 14)	(20, 12)	(21, 15)	(40, 30)	(56, 54)	(70, 59)	(95, 92)
(95, 93)	(103, 101)						

Worst: 84.4801

(18, 13)	(46, 28)	(52, 43)	(52, 46)	(54, 48)	(78, 34)	(95, 91)	(95, 92)

SSS_result2_1_10

100 # current generation
1.0017 # current convergence
15000 # number of selections since initialization
11078 # number of crossovers since initialization
227 # number of mutations since initialization
15000 # number of replacements since initialization
11438 # number of genome evaluations since initialization
101 # number of population evaluations since initialization
94.3163 # maximum score since initialization
56.566 # minimum score since initialization
58.026 # average of all scores ('on-line' performance)
58.2488 # average of maximum scores ('off-line' performance)
57.3228 # average of minimum scores ('off-line' performance)

67.1278 # mean score in initial population
94.3163 # maximum score in initial population
61.231 # minimum score in initial population
6.13988 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

56.5726 # mean score in current population
56.6623 # maximum score in current population
56.566 # minimum score in current population
0.0240788 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C:\GA experiements\GUI-iterative learning2\data_21\sss_gen2_1_10.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 10
Time elasped = 3569.16
Original: 63.4942

Best:	56.566						
(12, 10)	(15, 14)	(20, 12)	(21, 15)	(54, 48)	(70, 59)	(77, 37)	(90, 82)
(95, 92)	(95, 93)						
Worst:	94.3163						
(26, 25)	(29, 28)	(34, 24)	(44, 39)	(46, 28)	(54, 53)	(63, 52)	(77, 37)

SSS_result2_1_15

120 # current generation
1 # current convergence
13200 # number of selections since initialization
9872 # number of crossovers since initialization
221 # number of mutations since initialization
13200 # number of replacements since initialization
10144 # number of genome evaluations since initialization
121 # number of population evaluations since initialization
102.339 # maximum score since initialization
56.3727 # minimum score since initialization
57.4004 # average of all scores ('on-line' performance)
57.6205 # average of maximum scores ('off-line' performance)
56.8013 # average of minimum scores ('off-line' performance)

69.2125 # mean score in initial population
102.339 # maximum score in initial population
61.6284 # minimum score in initial population
7.84317 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

56.3728 # mean score in current population
56.3727 # maximum score in current population
56.3727 # minimum score in current population
9.17615e-005 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C:\GA experiements\GUI-iterative learning2 data_21\sss_gen2_1_15.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 15
Time elasped = 2306.31
Original: 63.9112
Best: 56.3727

(12, 10)	(15, 14)	(20, 12)	(21, 15)	(26, 24)	(42, 41)	(50, 45)	(54, 48)
(56, 54)	(63, 52)	(72, 31)	(77, 37)	(90, 82)	(95, 92)	(95, 93)	

Worst: 102.339

(18, 13)	(26, 24)	(29, 28)	(34, 24)	(38, 27)	(46, 28)	(50, 45)	(54, 53)
(63, 52)							

SSS_result2_1_20

120 # current generation
1 # current convergence
13200 # number of selections since initialization
10034 # number of crossovers since initialization
184 # number of mutations since initialization
13200 # number of replacements since initialization
10295 # number of genome evaluations since initialization
121 # number of population evaluations since initialization
95.7953 # maximum score since initialization
55.7608 # minimum score since initialization
56.9494 # average of all scores ('on-line' performance)
57.208 # average of maximum scores ('off-line' performance)
56.2781 # average of minimum scores ('off-line' performance)

70.1142 # mean score in initial population
95.7953 # maximum score in initial population
60.6813 # minimum score in initial population
8.35082 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

55.7607 # mean score in current population
55.7608 # maximum score in current population
55.7608 # minimum score in current population
3.8234e-005 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C:\GA experiements\GUI-iterative learning2\data_21\sss_gen2_1_20.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 20
Time elasped = 2504.55
Original: 63.5097
Best: 55.7608

(12, 10)	(15, 14)	(20, 12)	(21, 15)	(34, 24)	(38, 27)	(42, 41)	(46, 27)
(46, 28)	(49, 47)	(50, 46)	(52, 46)	(54, 48)	(56, 54)	(70, 59)	(72, 31)
(77, 37)	(90, 82)	(95, 92)	(95, 93)				

Worst: 95.7953

(12, 10)	(15, 14)	(18, 14)	(29, 28)	(34, 24)	(44, 39)	(46, 28)	(50, 46)
(52, 46)	(54, 34)	(64, 54)	(72, 31)	(83, 77)	(95, 91)		

SSS_result2_1_25

120 # current generation
1 # current convergence
15120 # number of selections since initialization
11170 # number of crossovers since initialization
224 # number of mutations since initialization
15000 # number of replacements since initialization
11475 # number of genome evaluations since initialization
121 # number of population evaluations since initialization
94.2667 # maximum score since initialization
53.9346 # minimum score since initialization
55.5495 # average of all scores ('on-line' performance)
55.8563 # average of maximum scores ('off-line' performance)
54.7825 # average of minimum scores ('off-line' performance)

70.938 # mean score in initial population
94.2667 # maximum score in initial population
60.6042 # minimum score in initial population
8.35091 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

53.9346 # mean score in current population
53.9346 # maximum score in current population
53.9346 # minimum score in current population
3.82235e-006 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C:\GA experiements\GUI-iterative learning2\data_21\sss_gen2_1_25.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 25
Time elasped = 2061.84
Original: 63.6909
Best: 53.9346

(12, 8)	(12, 10)	(13, 12)	(18, 13)	(18, 14)	(20, 12)	(21, 15)	(21, 17)
(22, 14)	(29, 26)	(33, 24)	(42, 41)	(49, 47)	(52, 43)	(54, 48)	(54, 53)
(63, 52)	(67, 64)	(70, 59)	(72, 31)	(77, 37)	(83, 77)	(90, 82)	(95, 92)
(95, 93)							

Worst: 94.2667

(21, 15)	(22, 14)	(26, 24)					
(54, 34)	(70, 59)	(90, 82)	(29, 28)	(30, 25)	(34, 24)	(38, 27)	(46, 27)

SSS_result2_1_30

120 # current generation
1 # current convergence
13200 # number of selections since initialization
9932 # number of crossovers since initialization
202 # number of mutations since initialization
13200 # number of replacements since initialization
10193 # number of genome evaluations since initialization
121 # number of population evaluations since initialization
99.8311 # maximum score since initialization
53.3425 # minimum score since initialization
55.3672 # average of all scores ('on-line' performance)
55.7529 # average of maximum scores ('off-line' performance)
54.3792 # average of minimum scores ('off-line' performance)

72.2953 # mean score in initial population
99.8311 # maximum score in initial population
59.1636 # minimum score in initial population
8.5812 # standard deviation of initial population
-1 # diversity of initial population (0=identical,-1=unset)

53.3425 # mean score in current population
53.3425 # maximum score in current population
53.3425 # minimum score in current population
3.8234e-005 # standard deviation of current population
-1 # diversity of current population (0=identical,-1=unset)

20 # how far back to look for convergence
1 # how often to record scores
1 # how often to write scores to file
C: GA experiements\GUI-iterative learning2 data_21\sss_gen2_1_30.txt # name of file to which scores are written

Total number of interdependant pairs: 49
Maximum number of links to break: 30
Time elasped = 2577.23
Original: 63.4393
Best: 53.3425

(12, 8)	(12, 10)	(13, 12)	(18, 13)	(18, 14)	(20, 12)	(21, 15)	(22, 14)
(26, 24)	(26, 25)	(29, 26)	(30, 25)	(33, 24)	(38, 27)	(42, 41)	(44, 39)
(46, 28)	(49, 47)	(52, 43)	(53, 50)	(54, 48)	(54, 53)	(70, 59)	(72, 31)
(77, 37)	(81, 77)	(83, 77)	(90, 82)	(95, 92)	(95, 93)		

Worst: 99.8311

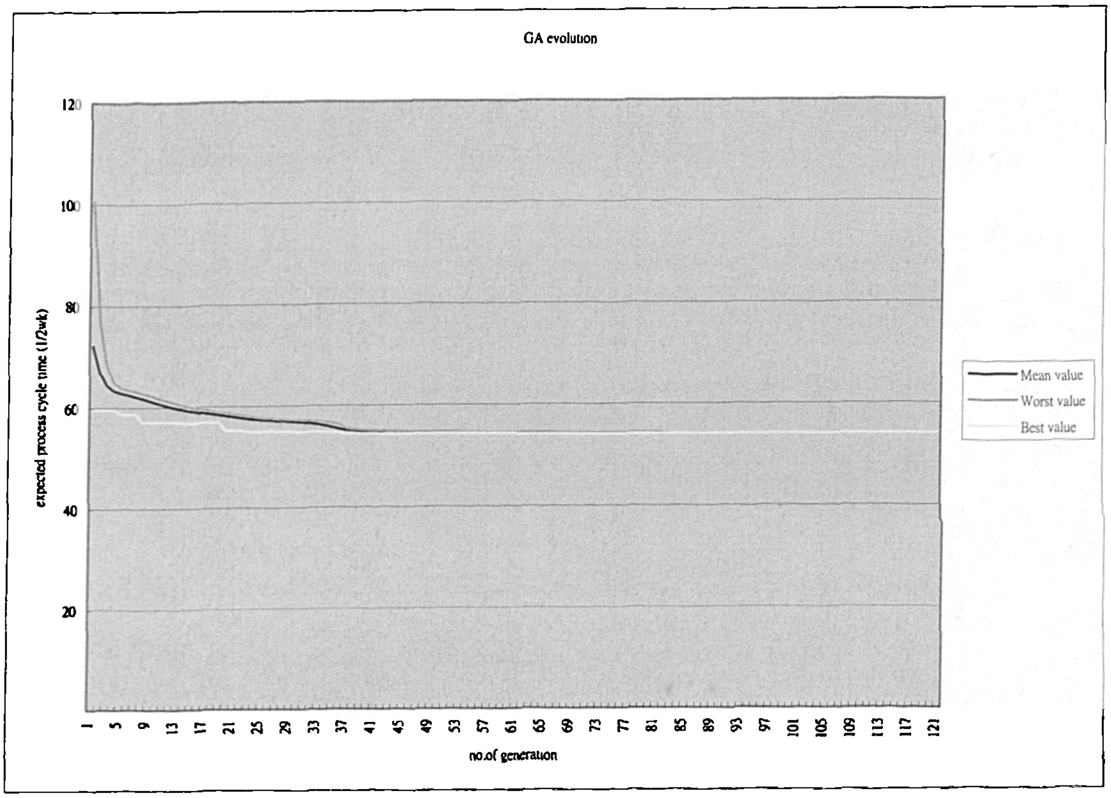
(13, 12)	(20, 12)	(22, 14)	(26, 24)	(26, 25)	(29, 26)	(29, 28)	(30, 25)
(33, 24)	(46, 27)	(47, 43)	(52, 43)	(54, 34)	(54, 48)	(56, 54)	(58, 54)
(58, 57)	(67, 64)	(70, 59)	(72, 31)	(78, 34)	(83, 77)	(95, 91)	(95, 92)
(95, 93)							

A.4 An example of the GA evolution from the evaluation result, SSS_result1_1_30

0	72.167	100.609	59.5481	8.45199	-1
1	66.9672	76.4544	59.5481	4.10578	-1
2	64.4087	68.5104	59.5481	1.8959	-1
3	63.3462	65	59.5481	1.06654	-1
4	62.855	63.9023	58.7634	1.01328	-1
5	62.5313	63.5455	58.7634	1.00298	-1
6	62.1597	63.287	58.7634	0.967979	-1
7	61.7777	62.7992	57.1389	0.945604	-1
8	61.3343	62.419	57.1389	0.935015	-1
9	60.8657	61.947	57.1389	0.946273	-1
10	60.4974	61.5337	57.1389	0.884795	-1
11	60.1274	61.1432	57.1389	0.785318	-1
12	59.8126	60.7222	57.1389	0.705924	-1
13	59.4732	60.3923	56.834	0.682232	-1
14	59.209	59.961	56.834	0.629723	-1
15	58.9396	59.6386	56.834	0.607277	-1
16	58.7216	59.404	56.834	0.561113	-1
17	58.5106	59.1026	56.834	0.533587	-1
18	58.3458	58.8761	56.834	0.492183	-1
19	58.1534	58.7569	55.2929	0.536507	-1
20	57.9585	58.5424	55.2929	0.502477	-1
21	57.7871	58.3993	55.2929	0.465227	-1
22	57.5845	58.1902	55.0274	0.434726	-1
23	57.4232	57.8992	55.0274	0.391289	-1
24	57.3017	57.7154	55.0183	0.396676	-1
25	57.2054	57.5534	55.0183	0.406374	-1
26	57.1312	57.4656	55.0183	0.422975	-1
27	57.0261	57.3691	55.0183	0.453073	-1
28	56.8941	57.2518	54.9028	0.535145	-1
29	56.7689	57.1985	54.8028	0.592905	-1
30	56.6764	57.1463	54.8028	0.618758	-1
31	56.4753	57.0712	54.8028	0.654608	-1
32	56.2961	56.9259	54.8028	0.671475	-1
33	56.0342	56.7857	54.8028	0.667121	-1
34	55.7396	56.6257	54.6861	0.62585	-1
35	55.3657	56.2757	54.6731	0.401193	-1
36	55.1595	55.5426	54.4286	0.229836	-1
37	55.042	55.2929	54.4077	0.19586	-1
38	54.9494	55.1875	54.4077	0.184526	-1
39	54.88	55.0973	54.4077	0.163183	-1
40	54.8103	55.0177	54.4077	0.15296	-1
41	54.7551	54.9257	54.3952	0.137616	-1
42	54.72	54.8689	54.3421	0.130614	-1
43	54.6911	54.831	54.3282	0.125695	-1
44	54.6618	54.8028	54.3282	0.114578	-1
45	54.6402	54.7643	54.3282	0.110394	-1
46	54.6157	54.7427	54.2963	0.106422	-1
47	54.5909	54.711	54.2761	0.107372	-1
48	54.5723	54.6901	54.2761	0.104963	-1
49	54.5482	54.6742	54.2761	0.100957	-1
50	54.5254	54.6464	54.2761	0.094909	-1
51	54.5047	54.6333	54.2761	0.087914	-1
52	54.4799	54.609	54.2761	0.079269	-1
53	54.4599	54.5702	54.2761	0.067666	-1
54	54.4365	54.525	54.2761	0.052458	-1

55	54.4182	54.4825	54.2761	0.042408	-1
56	54.4106	54.4538	54.2761	0.039377	-1
57	54.4028	54.4356	54.2761	0.041996	-1
58	54.3979	54.4286	54.2761	0.042669	-1
59	54.391	54.4286	54.2761	0.043509	-1
60	54.3833	54.4181	54.2761	0.043498	-1
61	54.3743	54.4173	54.0483	0.049394	-1
62	54.365	54.4077	54.0483	0.050558	-1
63	54.3587	54.4077	54.0483	0.050696	-1
64	54.345	54.4077	54.0483	0.051806	-1
65	54.3308	54.4059	54.0483	0.044811	-1
66	54.3149	54.3629	54.0483	0.040123	-1
67	54.3044	54.3421	54.0483	0.046608	-1
68	54.296	54.3282	54.0483	0.043373	-1
69	54.2855	54.3014	54.0483	0.05586	-1
70	54.2825	54.3014	54.0483	0.059714	-1
71	54.2799	54.3014	54.0483	0.061517	-1
72	54.2702	54.3014	54.0483	0.074147	-1
73	54.2644	54.3014	54.0158	0.079802	-1
74	54.2534	54.3014	54.0158	0.088808	-1
75	54.2409	54.3014	54.0158	0.095318	-1
76	54.2252	54.3014	54.0158	0.102138	-1
77	54.2056	54.2901	54.0158	0.108327	-1
78	54.1834	54.2849	54.0158	0.112687	-1
79	54.1474	54.2849	54.0158	0.111432	-1
80	54.11	54.2849	54.0158	0.09738	-1
81	54.0527	54.2202	54.0158	0.027641	-1
82	54.0464	54.0483	54.0158	0.007022	-1
83	54.0463	54.0483	54.0158	0.007306	-1
84	54.0461	54.0483	54.0158	0.007591	-1
85	54.0457	54.0483	54.0158	0.008281	-1
86	54.045	54.0483	54.0158	0.009281	-1
87	54.0439	54.0483	54.0158	0.010616	-1
88	54.0426	54.0483	54.0158	0.011807	-1
89	54.0418	54.0483	54.0158	0.012469	-1
90	54.0401	54.0483	54.0158	0.013531	-1
91	54.038	54.0483	54.0158	0.014494	-1
92	54.0355	54.0483	54.0158	0.01512	-1
93	54.0324	54.0483	54.0158	0.015519	-1
94	54.0269	54.0483	54.0158	0.014383	-1
95	54.0188	54.038	54.0158	0.007714	-1
96	54.0157	54.0158	54.0158	0.000107	-1
97	54.0157	54.0158	54.0158	0.000107	-1
98	54.0157	54.0158	54.0158	0.000107	-1
99	54.0157	54.0158	54.0158	0.000107	-1
100	54.0157	54.0158	54.0158	0.000107	-1
101	54.0157	54.0158	54.0158	0.000107	-1
102	54.0157	54.0158	54.0158	0.000107	-1
103	54.0157	54.0158	54.0158	0.000107	-1
104	54.0157	54.0158	54.0158	0.000107	-1
105	54.0157	54.0158	54.0158	0.000107	-1
106	54.0157	54.0158	54.0158	0.000107	-1
107	54.0157	54.0158	54.0158	0.000107	-1
108	54.0157	54.0158	54.0158	0.000107	-1
109	54.0157	54.0158	54.0158	0.000107	-1
110	54.0157	54.0158	54.0158	0.000107	-1
111	54.0157	54.0158	54.0158	0.000107	-1
112	54.0157	54.0158	54.0158	0.000107	-1

113	54.0157	54.0158	54.0158	0.000107	-1
114	54.0157	54.0158	54.0158	0.000107	-1
115	54.0157	54.0158	54.0158	0.000107	-1
116	54.0157	54.0158	54.0158	0.000107	-1
117	54.0157	54.0158	54.0158	0.000107	-1
118	54.0157	54.0158	54.0158	0.000107	-1
119	54.0157	54.0158	54.0158	0.000107	-1
120	54.0157	54.0158	54.0158	0.000107	-1



APPENDIX B: A QUESTIONNAIRE DESIGN AMD DATA TYPES FOR THE 103-ACTIVITY PROCESS CASE

Process Profile Study Questionnaire

Objectives:

This document is part of a research effort to understand better the product innovation processes in global fashion marketplaces and to illustrate the examples of best practices in planning and developing customer-oriented fashion products. Your careful completion of this form will entail quality results, mediating integrated business process systems needed to sustain the competitive success in the Asia-pacific region.

The purpose of this document is to collect some fairly extensive information on activity and information processes of product innovation in today's global fashion marketplaces. For consistence sakes, we shall use the specified names and terms as listed in the attachments. Please note that we may often use different process names to describe the same activity and communication process, based on our own experience. These individual understanding and use of process names may not be so consistent and make the response to this questionnaire very challenging. However, in this investigation, the activity and information process names comprising a global-scaled fashion and textile innovation activities have been studied and endeavored to generalize in order to make the information collection effort as reasonable and feasible as possible. Once you think some process names not so identified but absolutely essential to use in responding the questions, please specify them where necessary.

Please answer all the questions and provide the respective information to your best of knowledge. If you have a question that you think is special at your circumstance and would provide discretionary response for the activity, please give note about this briefly when necessary. Also if you have any query about how to respond to this document, please contact Chester To through e-mail : tctokm@polyu.edu.hk or phone number: 852-2766-6533.

Broadly speaking, fashion product innovation processes for global markets involve a number of business operational contexts, as illustrated in the following Figure 1, in which different business functionalities should be coordinated and run by companies across different places. Please refer to the figure and state the scope of core operation(s) your companies (or your teams) currently run. Meanwhile, please refer to the attached process name lists to respond to the following questions.

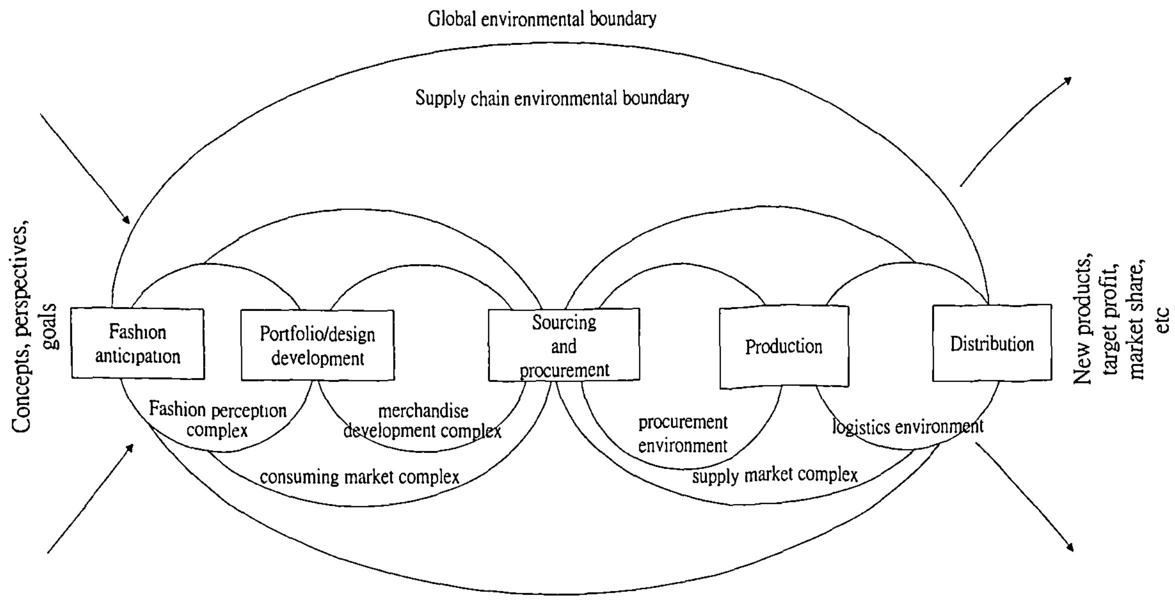


Figure 1 Contextual Process Elements for New Product Development in Gobal Fashion Businesses

The scope of operations : (tick those appropriate)

- ☐ Fashion Trend and Business Anticipation
- ☐ Portfolio and Prototype Development/
- ☐ Sourcing and Procurement/
- ☐ Production and Flow Management/
- ☐ Product Distribution

The main activity and communication processes (refer to the attached Process Chart) ____________________

Contact Name : ____________________

Contact (Phone number) : ____________________

(e-mail) : ____________________

Basically, each activity and communication process consists of more detailed processing aspects, like receiving input information or resources, processing and developing output information and materials, and also distributing the process outputs as sorts of documents or materials for further processing in next downstream activities. Please regard all these detailed processing aspects as single process as named. We attempt to categorize the processes into the essential functionalities of innovating fashion products and mainly consider the detailed process aspects as a whole.

Part A
Process Description

A1. Use your own words to describe briefly process es you have just stated. What are the functions and purposes of the process(es)? What are the essential sub-activities and communication processes?

Part B
Process inputs (resources and information)

To develop a useful activity and information process model for managing innovation activities in fashion businesses, we should understand what the key processes constitute the model system and how these processes interact with one another. Furthermore, we should know the types of information and resources needed as inputs to initiate a process and from where (the preceding processes) the information and resources come. Therefore, it is preferable to have all the relevant information and resource available from all the parties concerned.

Firstly you are requested to think carefully about the inputs absolutely essential to proceed the activity. Any changes of these inputs give rise to a large impact and the whole activity is required to restart. Also there are some supplementary inputs commonly nice to support and/or refine the process. Any changes result in partial rework of the activity. Meantime we would like you to see which inputs are only needed to verify, extend or ascertain the final decisions and actions of a process. Associated with these inputs, the sources of inputs (resources and/or information) are requested to indicate.

Very often, inter-activity dependencies can be attributive to organisational policies or strategic sharing of organisational resource, rather than merely the vitality of information exchanged. Such vitality of the input information should be associated with the organisational concerns, which comprise personal authorities, document formalities, rules, organisational politics and so forth. You are so requested to take them into account.

Resource and information inputs for the innovation process in fashion businesses have been broadly identified and listed in the attached document list. Making use of the respective inputs and the lists, you are requested to respond the following questions. If necessary, you would add, skip or amend the inputs listed where appropriate.

B1. What inputs are absolutely necessary and vital to proceed the activity? Any change of these will give rise to a large impact on the activity and the whole activity is required to rework.

In the column A, please indicate the types of inputs (both resources and information).

In the column B, identify the preceding processes from where the respective inputs come or provide. When there is multiple number of input sources for individual processes, please use "and" or "or" to show the commonality of preceding processes to these inputs.

In the column C, circle the appropriate scale to rate the anticipated possibility of which the inputs, after analyzed, compared or re-proceeded, are passed backwards to the preceding processes for re-work, re-schedule or re-verification. Scale 1 means nearly none of the information or resource feeding backward and the Scale 5 means the nearly absoluteness to feed the information or resource backwards to the processes. Scale nil means no such information and resource feeding backwards.

A		B	C
The inputs absolutely needed to proceed the activity		The preceding activities from which the inputs come	The possibility of which the inputs, after proceeded, are requested passing backwards
1			nil 1 - 2 - 3 - 4 - 5
2			nil 1 - 2 - 3 - 4 - 5
3			nil 1 - 2 - 3 - 4 - 5
4			nil 1 - 2 - 3 - 4 - 5
5			nil 1 - 2 - 3 - 4 - 5
6			nil 1 - 2 - 3 - 4 - 5

B2. What inputs are the supplementary inputs commonly nice to have to support the action and/or refine activity decisions? Any change of these will demand partial rework in the activity.

In the column A, please indicate the types of inputs (both resources and information).

In the column B, identify the preceding processes from where the respective inputs come or provide. When there is multiple number of input sources for individual processes, please use "and" or "or" to show the commonality of preceding processes to these inputs.

In the column C, circle the appropriate scale to rate the anticipated possibility of which the inputs, after analyzed, compared or re-proceeded, are passed backwards to the preceding processes for re-work, re-schedule or re-verification. Scale 1 means nearly none of the information or resource feeding backward and the Scale 5 means the nearly absoluteness to feed the information or resource backwards to the processes. Scale nil means no such information and resource feeding backwards.

A		B	C
The inputs that are commonly nice to have to support the process		The preceding activities from which the inputs come	The possibility of which the inputs, after proceeded, are requested passing backwards
1			nil 1 - 2 - 3 - 4 - 5
2			nil 1 - 2 - 3 - 4 - 5
3			nil 1 - 2 - 3 - 4 - 5
4			nil 1 - 2 - 3 - 4 - 5
5			nil 1 - 2 - 3 - 4 - 5
6			nil 1 - 2 - 3 - 4 - 5

B3. What inputs beyond those noted in B1 and B2 would help you optionally to verify actions and decisions in the activity? Any change of these inputs will result in the least impact and you may even decide not to re-work or re-work with the least effort.

In the column A, please indicate the types of inputs (both resources and information).

In the column B, identify the preceding processes from where the respective inputs come or provide. When there is multiple number of input sources for individual processes, please use "and" or "or" to show the commonality of preceding processes to these inputs.

In the column C, circle the appropriate scale to rate the anticipated possibility of which the inputs, after analyzed, compared or re-proceeded, are passed backwards to the preceding processes for re-work, re-schedule or re-verification. Scale 1 means nearly none of the information or resource feeding backward and the Scale 5 means the nearly absoluteness to feed the information or resource backwards to the processes. Scale nil means no such information and resource feeding backwards.

A		B	C
The inputs merely for verification of its completion and finalization		The preceding activities from which the inputs come	The possibility of which the inputs, after proceeded, are requested passing backwards
1			nil 1 - 2 - 3 - 4 - 5
2			nil 1 - 2 - 3 - 4 - 5
3			nil 1 - 2 - 3 - 4 - 5
4			nil 1 - 2 - 3 - 4 - 5
5			nil 1 - 2 - 3 - 4 - 5
6			nil 1 - 2 - 3 - 4 - 5

B4. How are the activities dependent on the inputs from organisational perspectives?

Further, in order for us to fully understand and measure the extent to which the activities depend on the corresponding inputs, we would like you to think carefully about sources of the inputs in B1, B2 and B3 and rate the dependencies from **organisation governance** perspective. Organisational governance treats dependency as arising from organisational and political aspects, like personal authorities, document formalities, control, rules, policies, autonomy, divisions of job, staff versatility and so on so forth. For pair of activities, if an activity has to start to proceed right after the completion of the other activity mainly due to these aspects, the interdependency is regarded to be strong. Contrarily, if activity is dependent on the other one, but this activity is allowed to proceed in parallel with the other activity to some certain extent, the dependency tends to be weak

In the column D of the following tables, circle the appropriate scale to rate the *organisational dependencies* for the inputs:

Scale 1 means the least level of interdependency due to some sorts of formality and you can be very confident to proceed work simultaneously with the dependent activities without much organisation and political constraints.

Scale 2 means moderate governance and you are allowed to proceed and overlap with the dependent activity upon the receipt of formal advice

Scale 3 means the highest level of interdependency, at which you have not to proceed work until you are proved to do so authoritatively or on some other organisation grounds.

Nil means no such existence of governance dependency

A	D
The inputs absolutely needed to proceed the activity	The interdependency that arise from some sorts of organisation and political constraints.
1	nil 1 - 2 - 3
2	nil 1 - 2 - 3
3	nil 1 - 2 - 3
4	nil 1 - 2 - 3
5	nil 1 - 2 - 3
6	nil 1 - 2 - 3

A	D
The inputs that are commonly nice to have to support the process	The interdependency that arise from some sorts of organisation and political constraints.
1	nil 1 - 2 - 3
2	nil 1 - 2 - 3
3	nil 1 - 2 - 3
4	nil 1 - 2 - 3
5	nil 1 - 2 - 3
6	1 - 2 - 3 - 4 - 5

A	D
The inputs merely for verification of its completion and finalization	The interdependency that arise from some sorts of organisation and political constraints.
1	nil 1 - 2 - 3
2	nil 1 - 2 - 3
3	nil 1 - 2 - 3
4	nil 1 - 2 - 3
5	nil 1 - 2 - 3
6	nil 1 - 2 - 3

Some activities beyond that stated as above exhibit a certain extent of governance for your activity to start. Please specify them below and circle the appropriate governance interdependency :

A	D
Activities	The interdependency that arise from some sorts of organisation and political constraints.
1	nil 1 - 2 - 3
2	nil 1 - 2 - 3
3	nil 1 - 2 - 3
4	nil 1 - 2 - 3
5	nil 1 - 2 - 3
6	nil 1 - 2 - 3

Part C.
Process Outputs

To understand better the functionalities of processes in the global based fashion supply pipeline, it is essential to know what the outputs would be in individual processes and how they disseminate out to succeeding processes. Think about all the information and resources this process is required to produce for downstream processes.

Resource and information outputs for the product innovation process in fashion businesses has been conclusively identified and listed in the attached document list. Making use of the respective outputs in the lists, you are requested to respond the following question. If necessary, you would add, skip or amend the inputs listed where appropriate.

C1. What information, resources, material or even operational policies does this process provide? Please choose from the list provided and mark below accordingly.

1	
2	
3	
4	
5	
6	
7	
8	

Part D.
Process Duration and Resource

Often activity and communication processes cannot be completed as scheduled. In most cases, the processes are extended because of some known process variations or unexpected accidents and operational failure. As such dependent processes are commonly hurried up intentionally to achieve faster or earlier. To consider how long a process takes in time and how much it costs, we should also think about how certain we can estimate in these regards. Please refer to your experience and answer the following questions in these aspects.

D1. Generally, estimate the time (in terms of number of days) that is commonly regarded necessary to complete the process.

_______________________________ days

D2. Estimate the proportion (in terms of percentage) of the D1 estimated process time that is spent collecting, organising and examining the usefulness and relevance of incoming information and resource inputs.

_______________________________ %

D3. Estimate the proportion (in terms of percentage) of the D1 estimated process time that is spent processing and transforming the incoming information and resources into outputs ready to serve for downstream processes.

_______________________________ %

D4. To your knowledge of exceptional cases, what is the least time that the process can be completed in the condition that input resources do not change?

_______________________________ days

D5. To your knowledge, what is the longest time?

_______________ days _______________

D6. Within the two extremes from <u>D4 to D5</u>, estimate the range of process time (in terms of days), in which the process can be completed successfully with 80% chance.

From _______________ to _______________ days

D7. Is it necessary or expected for task iterations and re-process? If yes, how many iterations or rework are usually expected for the process?

Yes/No; The number of iterations or rework : _______________

D8. What are the possible causes underlying the iterations or rework? Is they often or rare? Please rate the frequency by circling the scale from 1 to 5; 1 refers to the least frequent, 5 refers to the most frequent and nil means never.

Causes	Frequency
1	nil 1- 2 - 3 - 4 - 5
2	nil 1- 2 - 3 - 4 - 5
3	nil 1- 2 - 3 - 4 - 5
4	nil 1- 2 - 3 - 4 - 5
5	nil 1- 2 - 3 - 4 - 5

D9. The progress of process is partially subject to the resources that can be right allocated in that process. They may include some professionals or technical staff, or types of facility like hardware, services, equipment, software and so on. Please indicate the key resources:

People:
Number of staff, their disciplines, and their total contribution:
(e.g 4 full part designers 4 man-days)

1
2
3
4
5

Types of facility:
(e.g. 2 seasonal forecast publishing materials in USD150.00)

D10. Is the process often reworked, re-scheduled or re-proceeded because of the delay of availability of these resources. If yes, how often? Please rate the frequency by circling the scale from 1 to 5. Again, 1 refers to the least; 5 refers to the most frequent; and nil means never.

Yes/No ; nil 1 - 2 - 3 - 4 - 5

D11. Very often, the specific process inputs are requested to process several times. Referring to the questions B1, B2 and B3, once the process inputs are required passing backwards for reworking, estimate the proportion (in terms of percentage) of work you believe necessary to re-process as to the previous ones each time by circling the appropriate scale in column E as below:

A	E
The inputs absolutely needed to initiate the process	The proportion of the inputs that you estimate to re-proceed after each time they reciprocally provide
	0% 20% 40% 60% 80% 100%
1	nil 1 - 2 - 3 - 4 - 5
2	nil 1 - 2 - 3 - 4 - 5
3	nil 1 - 2 - 3 - 4 - 5
4	nil 1 - 2 - 3 - 4 - 5
5	nil 1 - 2 - 3 - 4 - 5

A	E
The inputs that is commonly nice to support the process	The proportion of the inputs that you estimate to re-proceed after each time they reciprocally provide
	0% 20% 40% 60% 80% 100%
1	nil 1 - 2 - 3 - 4 - 5
2	nil 1 - 2 - 3 - 4 - 5
3	nil 1 - 2 - 3 - 4 - 5
4	nil 1 - 2 - 3 - 4 - 5
5	nil 1 - 2 - 3 - 4 - 5

A		E
The inputs merely for verification of its completion and finalization		The proportion of the inputs that you estimate to re-proceed after each time they reciprocally provide
		0% 20% 40% 60% 80% 100%
1		nil 1 - 2 - 3 - 4 - 5
2		nil 1 - 2 - 3 - 4 - 5
3		nil 1 - 2 - 3 - 4 - 5
4		nil 1 - 2 - 3 - 4 - 5
5		nil 1 - 2 - 3 - 4 - 5

	Function teams	Tasks	Sub-task (document-based)
1	**Determine Business Trend Preference**	A111 Identify trend setters- fashion adoption	
2		A112 Examine novelty diffusion patterns	**121 Determine desirable life cycle time**
3			**122 Determine seasonal sales fluctuation**
4		A113 Measure market expectations	**131 Assess life styles of end-market users**
5			**132 Assess ethical issues in fashion markets**
6			**133 Assess technological advancement in fashion product alities**
7		A114 Remark contemporary socio-cultural issues and events	
8	**Determine Market Variables**	A121 Specify end-use consumers	**211 Segment consumer groups**
9			**212 Measure segments' market sizes**
10			**213 Measure consumption power and patterns**
11		A122 Examine distribution channels/outlet performance	**221 Examine distributors' performance**
12			**222 Examine store location profiles and performance**
13			**223 Measure competition profiles**
14		A123 Determine product profiles	**231 Assess brand profiles**
15			**232 Assess line profiles (depth and breath)**
16			**233 Measure complementary service/operation performance**
17	**Conceptualize Product Design**	A211 Budgeting	**111 Access and fix capital provisions**
18			**112 Determine costing policies**
19			**113 Determine markup-markdown policies**
20		A212 Design programme scale and collection frameworks	**121 Plan on-floor product distribution cycle and schedules**
21			**122 Determine seasonal volume and buffers**
22		A213 Position product values/benefits	**131 Develop/adapt logos and labels**
23			**132 Design/develop visual merchandising**
24		A214 Design product features	**141 Design material types and fabrications**
25			**142 Design styling and story frames**
26			**143 Design construction methods and workmanship level**
27			**144 Design colourway/line combos**
28			**145 Select care instructions and tag-on materials**
29		A215 Establish quality standard and policies	
30		A216 Develop portfolio sketches	
31	**Examine Regulatory Aspects**	A231 Examine environmental and safety requirements	**311 Evaluate and select dying processes**

32			312 Evaluate and select add-ins finishing properties
33		A232 Examine overall collection image and quality consistence	
34		A233 Examine the detailed trade restrictions and practices	331 Evaluate and select control quota categories
35			332 Evaluate contemporary tariff and duty restrictions
36			333 Examine contemporary blacklisted materials & finishings
37	Consolidate Market Requirements	A241 Product screening and modifications	411 Fitting and sizing
38			412 Evaluate colourways, prints, frames, silhouette
39			413 Streamline collection components
40		A242 Consolidate market feedback and order quantity	421 Arrange collection presentation, trade shows
41			422 Prepare catalogs
42			423 Revise collection breakdown
43			424 Re-schedule material consumption & delivery
44		A243 Confirm seasonal portfolio and sale capacity	431 Open PDM files and item digital IDs
45			432 Consent delivery schedule
46			433 Conclude material specification and variation allowance
47		A244 Issue buying plans and buying buffers	
48		A245 Determine procurement tactic and policies	
49		A246 Determine contingent orders for market uncertainties	
50	Determine Sourcing Metrics	A311 Determine potential supply countries	111 Evaluate materials/quantity availability in countries
51			112 Project uncertainty
52			113 Design materials/production workflow process amongst s
53			114 Evaluate and optimize cost and lead-time
54		A312 Allocate proportion of purchase orders to potential suppliers	
55		A313 Assess individual supplier performance	
56		A314 Decide critical order placement criteria	
57	Determine Sourcing Channels and Coordination	A321 Compare and develop sourcing channels	211 Accredit suppliers and open supply account
58			212 Determine contractual terms & relationships
59			213 Develop affiliated sourcing agents and offices
60			214 Evaluate logistics performance decisions
61		A322 Determine coordination and control mechanisms	221 Install communication infrastructure
62			222 Design communication procedures/documentation
63		A323 Assign buying teams duties and supply site visits	

64	Negotiate Order terms	A331 Negotiate delivery terms - conditions	
65		A332 Adjust allocation of purchase orders	
66		A333 Adjust order details	
67	Proceed Order placement	A341 Enter into procurement contract	
68		A342 Work out credit loan facilities	
69		A343 Select financial supports and estimate periodic capital return	
70		A344 Plan credit sources (undertakings)	
71		A345 Confirm credit issuance	
72	Embody Product Design	A401 Make prototype samples	011 Make fabric strikeoff
73			012 Make accessory samples
74			013 Make colour lab-dips
75			014 Evaluate material properties and potential problems
76			015 Evaluate finishing and/or washing processes
77			016 Make garment samples
78			017 Evaluate fibre components
79		A402 Develop collection and salesman samples	
80		A403 Establish testing standards and technical specifications	
81	Organize Production Processes	A411 Plan manufacturing processes	111 Engineer patterns/markers/grading
82			112 Engineer cutting process
83			113 Engineer line balancing and component flows
84			114 Design pack and finishing works
85			115 Engineer machine setting
86			116 Engineer plant layout
87		A412 Make approval samples	
88		A413 Estimate material utilization	
89		A414 Material requisition	
90		A415 Machine/equipment requisition	
91		A416 Assign jobshop loading	
92	Monitor Production Quality/Progress	A421 Design in-line inspection methods	
93		A422 Design final inspection methods	
94		A423 Develop inspection systems and procedure	
95		A424 Audit and amend quality-related variation	
96	Coordinate Auxiliary Services	A431 Decide levels of automation and WIP processing	
97		A432 Design documentation and expedition procedure	

98		A433 Plan/restructure functional staff	
99	**Schedule Traffics**	A511 Schedule carrier rota	**5111 Estimate seasonal ship capacity**
100			**5112 Negotiate chartering terms**
101			**5113 Assign sale digital barcode**
102	**Coordinate Logistic Works**	A520 Document inventory information	
103		A530 Construct accounting and financial systems	

Information List for Global-oriented Product Innovation in Fashion Businesses

			data sets
Market decision variables			
MDV_1_	Consumer forecast	numericals	gender(female/male/teenage), market classes (mass/high), ceiling prices(low,medium, high), markup ratio(>=target rate)
MDV_2_	Seasonality	integer	number of business seasons
MDV_3_	Budegt and Costing	value	monthly sell breakdown, interest rate, loan facility
MDV_4_	Market growth plan	percentage	SKU increase rate
MDV_5_	Market restrictiveness	policies	Operational tabu(restricted items)
MDV_6_	Branding/pricing plans	integer	number of private lables and national labels
MDV_7_	Merchandise plans	integer	number of lines, items, colourways, sizeways
MDV_8_	Distribution channel support	policies	type of retail modes(chain, exclusive, consignment, specialty, general stores)
MDV_9_	Epected portfolio novelty	policies	type of novelties(store/designer brands,life styles, function performances, individualistics)
MDV_10_			
MDV_OTHER_			
Logistic decision variables			
LDV_1_	Packaging	policies	type of pack(flat/hanger, basic/luxury, assorted/single)
LDV_2_	Assortment plans	policies	weight, number of colour/size, size
LDV_3_	Handling & transportation modes	policies	handling effort(cross-docking, replenishing pack)
LDV_4_	Replenishment approach & rate	value	frequency of replenishment(low/medium/high/null)
LDV_5_	Inventory provision	value	level of inventory and level of acquisition(fast, medium, slow moving items)
LDV_6_	Merchandise sorting and barcoding	policies	sell life cycle (running/ trendy fashion)
LDV_7_	Freight rate and insurance	value	distribution costs(low/medium/high)
LDV_8_	Delivery leadtime & scheduling	policies	distribution time(short/medium/long)
LDV_9_	Chartering capacity	value	shipping capacity(chartering time, rounte, rate)
LDV_10_	Import-export regulations/control	policies	control system types(EA, quota, duties)
LDV_11_			
LDV_OTHER_			
Product styling variables			
PSV_1_	Weight	value	
PSV_2_	Silhouette	policies	theme (look,image stories)
PSV_3_	Color variety	policies	colourway (wide/narrow)
PSV_4_	Visual complexity	policies	coordination (causal/learning/coordinating/formal)
PSV_5_	Texture	policies	emotional touch (warm/cool/initmate/soft/hard)
PSV_6_	Luxuriance	policies	perceived value
PSV_7_	Expected inspiration	policies	perceived value
PSV_8_	Easiness-for-coordinate	policies	functionalities
PSV_9_	Cover/porosity	policies	cultural/climate elements
PSV_10_	Fitness	policies	theme (look,image stories)
PSV_11_	Comfort	policies	functionalities
PSV_12_	Handfeel preference	policies	physical touch (warm/cool/initmate/soft/hard)
PSV_13_	Trendiness	policies	fashionalties
PSV_14_			
PSV_OTHER_			

Manufacturing variables			
MV_1_	Throughput-yarn fabrication	numericals	number of days
MV_2_	Throughput-fabric fabrication	numericals	number of days
MV_3_	Throughput-dye and finishing	numericals	number of days
MV_4_	Throughput-garment assembly	numericals	number of days
MV_5_	Quality variation	percentage	AQL
MV_6_	Production process specification	policies	engineering data
MV_7_	In-progress Inspection Scheme and standards	policies	standards
MV_8_	Consumer safety and ethic policies	policies	standards
MV_9_	Assembly requirements	policies	engineering data
MV_10_	Capital/labour intensiveness	policies	engineering data
MV_11_	Production line capacity & adaptability	numericals	outputs
MV_12_	Skill content	policies	engineering data
MV_13_	Bill of materials	policies	stock and acquisition progress
MV_14_	CMT	value	Cost-Make-Trim
Merchandise variables			
MCV_!_	Suppliers' capacity	numericals	order allocation priority(low, medium, high)
MCV_2_	Portfolio	policies	theme reference
MCV_3_	Bills of fabric & accessories	policies	fabric & materials purchasing
MCV_4_	Garment specifictions	policies	engineering data
MCV_5_	Customs regulation updates	policies	standards
MCV_6_	Care instruction standards	policies	standards
MCV_7_	Size & sizing	policies	technical data (market class)
Technical performance variables			
PPV_1_	Fabric types and structures	policies	engineering data
PPV_2_	Accessory types and structures	policies	engineering data
PPV_3_	Material costs	value	costing
PPV_4_	Shrinkage	percentage	standards
PPV_5_	Resistance to perspiration	numericals	standards
PPV_6_	Resistence to Mildew/dampness	numericals	standards
PPV_7_	Resistance to chemicals	numericals	standards
PPV_8_	Overall colour fastness	numericals	standards
PPV_9_	Windproof	numericals	standards
PPV_10_	Waterproof	numericals	standards
PPV_11_	Flame retardency	numericals	standards
PPV_12_	Seam-stitch strength	numericals	standards
PPV_13_	Elasticity (shape resilience)	numericals	standards
PPV_14_			
PPV_15_			
PPV_OTHER_			